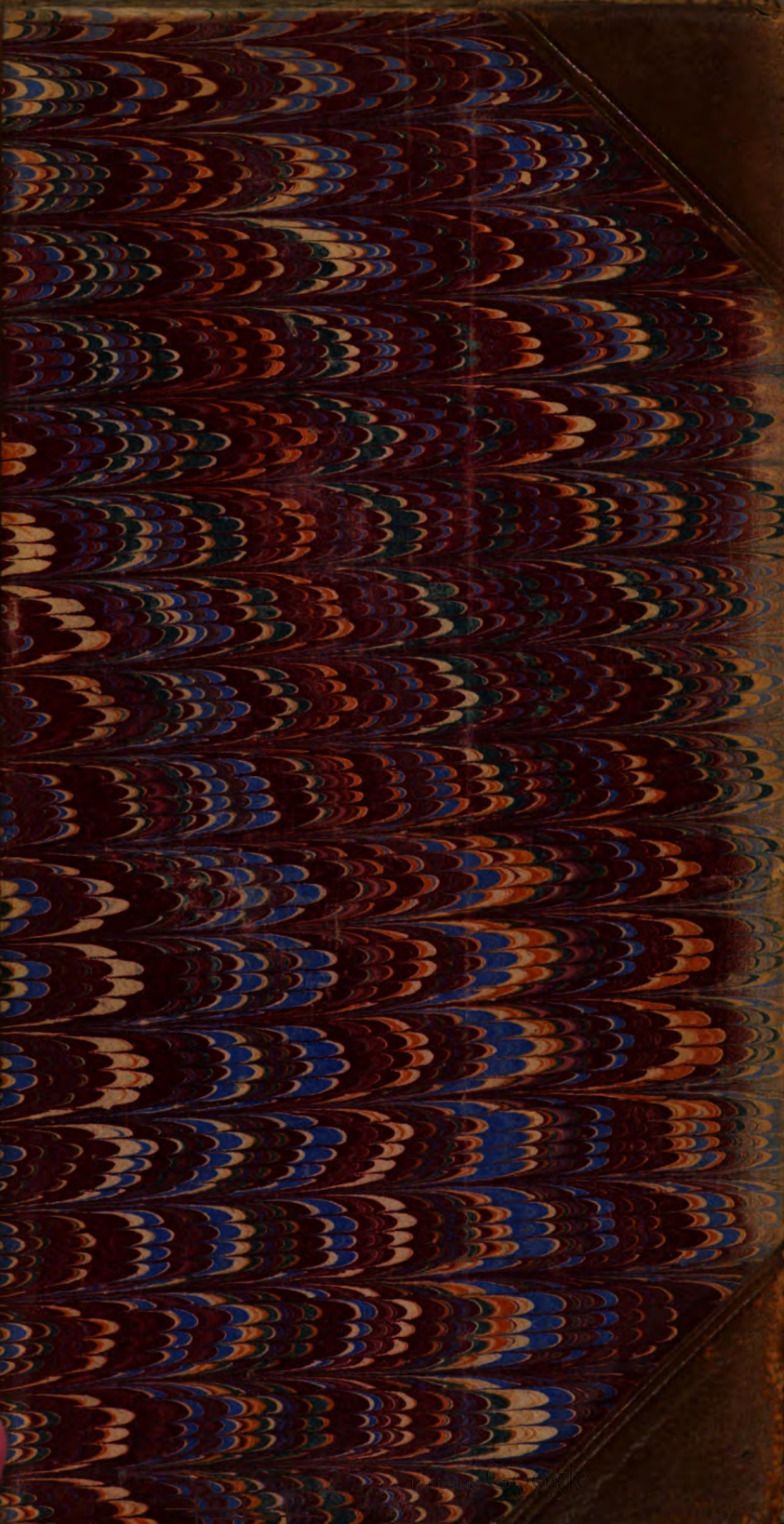

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INSTITUTION
OF
MECHANICAL ENGINEERS.

PROCEEDINGS.

1862.

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1862.



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C O U N C I L , 1 8 6 2 .

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Birmingham and Midland Bank, Birmingham.

Secretary.

WILLIAM P. MARSHALL,
*Institution of Mechanical Engineers,
81 Newhall Street, Birmingham.*

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1862.

LIFE MEMBERS.

1852. Brogden, Henry, Sale, near Manchester.
1858. Fletcher, Henry Allason, Lowca Engine Works, Whitehaven.
1857. Haughton, S. Wilfred, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham.
1853. Maudslay, Henry, Cheltenham Place, Lambeth, London, S.
1848. Penn, John, The Cedars, Lee, Kent, S.E.

MEMBERS.

1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1848. Adams, William Alexander, Midland Works, Birmingham.
1859. Adamson, Daniel, Newton Moor Iron Works, Hyde, near Manchester.
1861. Addenbrooke, George, Rough Hay Furnaces, Darlaston, near Wednesbury.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt, Oise, France.
1847. Allan, Alexander, Locomotive Superintendent, Scottish Central Railway, Perth.
1856. Allen, Edward Ellis, 5 Parliament Street, Westminster, S.W.
1856. Allen, James, Cambridge Street Works, Manchester.
1859. Alton, George, Midland Railway Works, Derby.
1861. Amos, Charles Edwards, Grove Works, Southwark, London, S.E.
1856. Anderson, John, Assistant Superintendent, Royal Gun Factories, Royal Arsenal, Woolwich, S.E.
1856. Anderson, William, Messrs. Courtney Stephens and Co., Blackall Place Iron Works, Dublin.
1862. Angus, Robert, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.
1858. Appleby, Charles Edward, Mining Engineer, 3 London Terrace, Derby.
1861. Armitage, Harry W., Farnley Iron Works, Leeds.
1859. Armitage, William James, Farnley Iron Works, Leeds.

1857. Armstrong, Joseph, Great Western Railway, Locomotive Department, Wolverhampton.
1858. Armstrong, Sir William George, Elswick, Newcastle-on-Tyne.
1857. Ashbury, James Lloyd, Openshaw Works, near Manchester.
1848. Ashbury, John, Openshaw Works, near Manchester.
1858. Atkinson, Charles, Fitzalan Steel Works, Sheffield.
1848. Bagnall, William, Gold's Hill Iron Works, Westbromwich.
1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.
1848. Baker, William, London and North Western Railway, Euston Station, London, N.W.
1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.
1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1862. Barrow, Joseph, Wellington Foundry, Leeds.
1862. Barton, Edward, Rutland Steel Works, Sheffield.
1847. Barwell, William Harrison, Eagle Foundry, Northampton.
1859. Bastow, Samuel, Cliff House Iron Works, West Hartlepool.
1860. Batho, William Fothergill, Bordesley Works, Birmingham.
1859. Beacock, Robert, Victoria Foundry, Leeds.
1860. Beale, William Phipson, Parkgate Iron Works, Rotherham.
1848. Beattie, Joseph, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.
1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington.
1860. Beck, Richard, Lister Works, Upper Holloway, London, N.
1862. Beckett, Henry, Mining Engineer, Upper Penn, Wolverhampton.
1858. Bell, Isaac Lothian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne.
1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.
1854. Bennett, Peter Duckworth, Spon Lane Iron Works, Westbromwich.
1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.
1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton, near Manchester.
1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.
1847. Birley, Henry, Haigh Foundry, near Wigan.
1856. Blackburn, Isaac, Witton Park Iron Works, Darlington.
1851. Blackwell, Samuel Holden, Russell's Hall Iron Works, near Dudley.
1862. Blake, Henry Wollaston, Messrs. James Watt and Co., 18 London Street, London, E.C.
1862. Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.
1862. Bouch, Thomas, 78 George Street, Edinburgh.
1858. Bouch, William, Shildon Engine Works, Darlington.
1847. Bovill, George Hinton, Durnsford Lodge, Wandsworth, Surrey, S.W.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.
1862. Boyd, Nelson, Mining Engineer, Hartington, near Ashbourne.
1854. Bragge, William, Atlas Steel Works, Sheffield.
1854. Bramwell, Frederick Joseph, 35A Great George Street, Westminster, S.W.
1856. Bray, Edwin, Nevill Holt, near Market Harborough.
1861. Brierly, Henry, 27 Southampton Buildings, London, W.C.
1848. Broad, Robert, Horseley Iron Works, near Tipton.
1847. Brown, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1850. Brown, John, Atlas Steel Works, Sheffield.
1855. Brown, John, Mining Engineer, Barnsley.
1856. Brown, John, Mining Engineer, Bank Top, Darlington.
1853. Brown, Ralph, Patent Shaft Works, Wednesbury.
1858. Burn, Henry, Midland Railway, Locomotive Department, Sheffield.
1856. Butler, Ambrose Edmund, Kirkstall Forge, Leeds.
1859. Butler, John, Old Foundry, Stanningley, near Leeds.
1859. Butler, John Octavius, Kirkstall Forge, Leeds.
1857. Cabry, Joseph, Midland Great Western Railway, Dublin
1847. Cabry, Thomas, North Eastern Railway, York.
1847. Cammell, Charles, Cyclops Steel Works, Sheffield.
1860. Cannell, Fleetwood James, Old Park Iron Works, Wednesbury.
1860. Carbutt, Edward Hamer, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1862. Carpmael, William, 24 Southampton Buildings, London, W.C.
1856. Carrett, William Elliott, Sun Foundry, Leeds.
1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.
1849. Chamberlain, Humphrey, 3 St. John's, Wakefield.
1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.
1854. Clark, Daniel Kinnear, 11 Adam Street, Adelphi, London, W.C.
1859. Clark, George, Monkwearmouth Engine Works, Sunderland.
1862. Clark, James, Wellington Foundry, Leeds.
1859. Clay, William, Mersey Steel and Iron Works, Sefton Street, Liverpool.
1847. Clift, John Edward, Durnford Place, Coventry Road, Birmingham.
1860. Clunes, Thomas, Vulcan Iron Works, Worcester.
1847. Cochrane, Alexander Brodie, Woodside Iron Works, near Dudley.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley.
1860. Cochrane, Henry, Ormesby Iron Works, Middlesbrough.
1854. Cochrane, John, Woodside Iron Works, near Dudley.
1847. Coke, Richard George, Mining Engineer, 6 Market Hall Chambers, Chesterfield.

1853. Cooper, Samuel Thomas, Leeds Iron Works, Leeds.
1860. Cope, James, Mining Engineer, Pensnett, near Dudley.
1848. Corry, Edward, 8 New Broad Street, London, E.C.
1857. Cortazzi, Francis James, Locomotive Superintendent, Great Indian Peninsula Railway, Bombay: (or care of T. D. Hornby, 4 Exchange Buildings, Liverpool.)
1860. Coulthard, Hiram Craven, Park Iron Works, Blackburn.
1860. Cowie, David, Engine Works, Abo, Finland.
1847. Cowper, Edward Alfred, 35A Great George Street, Westminster, S.W.
1862. Cox, Samuel H. F., 6 St. John's Road, Putney, London, S.W.
1853. Craig, William Grindley, 14 Cannon Street, London, E.C.
1847. Crampton, Thomas Russell, 12 Great George Street, Westminster, S.W.
1858. Crawhall, Joseph, St. Ann's Wire and Hemp Rope Works, Newcastle-on-Tyne.
1857. Criswick, Theophilus, Plymouth Iron Works, Merthyr Tydvil.
1858. Cubitt, Charles, 3 Great George Street, Westminster, S.W.

1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1860. Dawes, William Henry, Bromford Iron Works, Westbromwich.
1861. Dawson, Benjamin, Engineer, West Hetton Collieries, near Ferryhill.
1862. Deakin, William, Monmer Lane Iron Works, Willenhall, near Wolverhampton.
1857. De Bergue, Charles, Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1859. Dixon, John, Railway Foundry, Bradford, Yorkshire.
1861. Dixon, Thomas, Low Moor Iron Works, near Bradford, Yorkshire.
1854. Dodds, Thomas W., Holmes Engine Works, Rotherham.
1857. Douglas, George K., Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
1857. Dove, George, St. Nicholas and Woodbank Iron Works, Carlisle.
1856. Dudgeon, John, Sun Iron Works, Millwall, London, E.
1856. Dudgeon, William, Sun Iron Works, Millwall, London, E.
1857. Dunlop, John Macmillan, Marlborough Street, Oxford Street, Manchester.
1854. Dunn, Thomas, Windsor Bridge Iron Works, Manchester.
1861. Dutton, Charles, Bromford Iron Works, Westbromwich.
1860. Dyson, George, Tudhoe Iron Works, near Ferryhill.

1859. Eassie, Peter Boyd, Saw Mills, High Orchard, Gloucester.
1858. Easton, Edward, Grove Works, Southwark, London, S.E.
1856. Eastwood, James, Railway Iron Works, Derby.
1859. Egleston, Thomas, Jun., 10 Fifth Avenue, New York.
1862. Elder, John, Messrs. Randolph Elder and Co., Centre Street, Glasgow.

1859. Elliot, George, Houghton-le-Spring, near Fence Houses.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Poulot, 9 Avenue Trudaine, Paris.
1853. England, George, Hatcham Iron Works, London, S.E.
1861. Esson, William, Engineer, Cheltenham Gas Works, Cheltenham.
1857. Evans, John Campbell, Morden Iron Works, East Greenwich, S.E.
1848. Everitt, George Allen, Kingston Metal Works, Adderley Street, Birmingham.
1857. Fairlie, Robert Francis, 56 Gracechurch Street, London, E.C.
1862. Farmer, John, Shut End Iron Works, near Dudley.
1861. Fearnley, Thomas, Globe Works, Hall Lane, Bradford, Yorkshire.
1847. Fenton, James, Low Moor Iron Works, near Bradford, Yorkshire.
1854. Fernie, John, Midland Railway, Locomotive Department, Derby.
1862. Field, Joshua, 6 Cheltenham Place, Lambeth, London, S.
1861. Field, Joshua, Jun., Cheltenham Place, Lambeth, London, S.
1861. Fleetwood, Daniel Joseph, Metal Rolling Mills, Icknield Port Road, Birmingham.
1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.
1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1859. Fogg, Robert, 17 Park Street, Westminster, S.W.
1861. Forster, Edward, Spon Lane Glass Works, near Birmingham.
1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.
1861. Foster, Sampson Lloyd, Old Park Iron Works, Wednesbury.
1847. Fothergill, Benjamin, 65 Cannon Street, London, E.C.
1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.
1857. Fowler, John, Steam Plough Works, Leeds.
1847. Fox, Sir Charles, 8 New Street, Spring Gardens, London, S.W.
1859. Fraser, John, Resident Engineer, Leeds Bradford and Halifax Junction Railway, Leeds.
1853. Fraser, Joseph Boyes, Alma Place, Kenilworth.
1856. Freeman, Joseph, 22 Cannon Street, London, E.C.
1852. Froude, William, Elmsleigh, Paignton, Torquay.
1862. Galton, Capt. Douglas, R. E., War Office, Pall Mall, London, S.W.
1847. Garland, William S., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1848. Gibbons, Benjamin, Hill Hampton House, near Stourport.
1860. Gibbons, Benjamin, Jun., Athol House, Edgbaston, Birmingham.
1856. Gilkes, Edgar, Tees Engine Works, Middlesborough.
1862. Godfrey, Samuel, Messrs. Bolckow and Vaughan's Iron Works, Middlesborough.

1854. Goode, Benjamin W., St. Paul's Square, Birmingham.
1847. Goodfellow, Benjamin, Hyde Iron Works, Hyde, near Manchester.
1848. Green, Charles, Tube Works, Leek Street, Birmingham.
1861. Green, Edward, Jun., 3 Bank Street, Exchange, Manchester.
1858. Greenwood, Thomas, Albion Foundry, Leeds.
1857. Gregory, John, Engineer, Portuguese National Railway South of Tagus, Barriero, near Lisbon.
1860. Grice, Frederic Groom, Stour Valley Works, Spon Lane, Westbromwich.
1861. Haden, William, Dixon's Green, Dudley.
1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.
1857. Hall, William, Bloomfield Iron Works, Tipton.
1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, Birmingham.
1858. Harding, John, Beeston Manor Iron Works, Leeds.
1859. Harman, Henry William, Canal Street Works, Manchester.
1856. Harrison, George, Canada Works, Birkenhead.
1858. Harrison, Thomas Elliot, North Eastern Railway, Newcastle-on-Tyne.
1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.
1861. Hawkins, William Bailey, 38 Dowgate Hill Chambers, Cannon Street, London, E.C.
1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.
1848. Hawthorn, Robert, Forth Banks, Newcastle-on-Tyne.
1848. Hawthorn, William, Forth Banks, Newcastle-on-Tyne.
1862. Haynes, Thomas John, Engineer and Shipbuilder, Cadiz.
1860. Head, John, Messrs. Ransomes and Sims, Orwell Works, Ipswich.
1858. Head, Thomas Howard, Teesdale Iron Works, Stockton-on-Tees.
1853. Headly, James Ind, Eagle Works, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1862. Heath, William J. W., Colombo, Ceylon: (or care of John J. Heath, 105 Vyse Street, Birmingham.)
1860. Heaton, George, Royal Copper Mint, Icknield Street East, Birmingham.
1858. Hedley, John, Houghton-le-Spring, near Fence Houses.
1848. Hewitson, William Watson, Airedale Foundry, Leeds.
1862. Hingley, Samuel, Hart's Hill Iron Works, near Brierley Hill.
1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.
1852. Holcroft, James, Shut End, Brierley Hill.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
1860. Hopkins, James Innes, Tees Side Iron Works, Middlesborough.
1856. Hopkinson, John, Messrs. Wren and Hopkinson, Altrincham Street, Manchester.
1858. Hopper, George, Houghton-le-Spring Iron Works, near Fence Houses.

1851. Horton, Joshua, Ætna Works, Smethwick, near Birmingham.
1858. Horsley, William, Jun., Hartley Engine Works, Seaton Sluice, near North Shields.
1858. Hosking, John, Gateshead Iron Works, Gateshead.
1860. Howard, James, Britannia Iron Works, Bedford.
1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.
1847. Howell, Joseph, Hawarden Iron Works, Holywell.
1861. Howell, Joseph Bennett, Hartford Steel Works, Sheffield.
1862. Huber, Peter Emile, Vogelhutte, Zurich.
1861. Huffam, Frederick Thomas, Messrs. Slaughter Gruning and Co., Avonside Iron Works, Bristol.
1857. Humber, William, 20 Abingdon Street, Westminster, S.W.
1847. Humphrys, Edward, Deptford Pier, London, S.E. .
1859. Hunt, James P., Corngreaves Iron Works, Corngreaves, near Birmingham.
1856. Hunt, Thomas, Tudela and Bilboa Railway, Bilboa: (or care of James Hunt, Crewe.)
1862. Hunter, Michael, Jun., Talbot Works, Johnson Street, Sheffield.
1860. Hurry, Henry C., Engineer, West Midland Railway, Worcester.
1857. Inshaw, John, Engine Works, Morville Street, Birmingham.
1859. Jackson, Matthew Murray, Messrs. Escher Wyss and Co., Engine Works, Zurich.
1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.
1861. Jackson, Robert, Ætna Steel Works, Sheffield.
1860. Jackson, Samuel, Cyclops Steel Works, Sheffield.
1858. Jaffrey, George William, Hartlepool Iron Works, Hartlepool.
1856. James, Jabez, 28A Broadwall, Stamford Street, Lambeth, London, S.
1855. Jeffcock, Parkin, Mining Engineer, Midland Road, Derby.
1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
1857. Jenkins, William, Locomotive Superintendent, Lancashire and Yorkshire Railway, Miles Platting, Manchester.
1861. Jessop, Sydney, Park Steel Works, Sheffield.
1861. Jessop, Thomas, Park Steel Works, Sheffield.
1854. Jobson, John, Derwent Foundry, Derby.
1847. Jobson, Robert, Dudley.
1847. Johnson, James, Great Northern Railway, Locomotive Department, Peterborough.
1848. Johnson, Richard William, Oldbury Carriage Works, near Birmingham.
1861. Johnson, Samuel Waite, Engineer, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1849. Johnson, William, 166 Buchanan Street, Glasgow.
1855. Johnson, William Beckett, Woodland's Bank, Altrincham, near Manchester.

1861. Jones, Alfred, Herbert's Park Iron Works, Bilston.
1861. Jones, David, Engineer, Rumney Railway, Machen, near Newport, Monmouthshire.
1847. Jones, Edward, Old Park Iron Works, Wednesbury.
1857. Jones, John Hodgson, 26 Great George Street, Westminster, S.W.
1853. Joy, David, Cleveland Engine Works, Middlesborough.
1857. Kay, James Clarkson, Phoenix Foundry, Bury, Lancashire.
1857. Kendall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near North Shields.
1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1857. Kennedy, Lt.-Colonel John Pitt, Engineer, Bombay Baroda and Central Indian Railway; 10 Liverpool Street, New Broad Street, London, E.C.
1848. Kirkham, John, 109 Euston Road, London, N.W.
1847. Kirtley, Matthew, Locomotive Superintendent, Midland Railway, Derby.
1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.
1848. Kitson, James, Airedale Foundry, Leeds.
1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.
1862. Knott, Joseph, Pennington Cotton Mill, Leigh, near Manchester.
1860. Law, David, Phoenix Iron Works, Glasgow.
1857. Laybourn, John, Isca Foundry, Newport, Monmouthshire.
1856. Laybourn, Richard, Locomotive Superintendent, Monmouthshire Railway and Canal Company, Newport, Monmouthshire.
1860. Lea, Henry, 33 Waterloo Street, Birmingham.
1862. Lee, J. C. Frank, 30 Parliament Street, Westminster, S.W.
1860. Lee, John, Victoria Foundry, Litchurch, near Derby.
1857. Lees, Sylvester, Locomotive Superintendent, East Lancashire Railway, Bury, Lancashire.
1858. Leslie, Andrew, Iron Ship Building Yard, Hebburn Quay, Gateshead.
1856. Levick, Frederick, Cwm-Celyn Blaina and Coalbrook Vale Iron Works, near Newport, Monmouthshire.
1860. Lewis, Thomas William, Plymouth Iron Works, Merthyr Tydvil.
1856. Linn, Alexander Grainger, Lynn.
1857. Little, Charles, Beehive Mills, Thornton Road, Bradford, Yorkshire.
1862. Lloyd, John, Lilleshall Iron Works, near Wellington, Shropshire.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury.
1852. Lloyd, Samuel, Old Park Iron Works, Wednesbury.
1862. Lloyd, Wilson, Old Park Iron Works, Wednesbury.
1856. Longridge, Robert Bewick, Steam Boiler Assurance Company, New Brown Street, Market Street, Manchester.
1859. Lord, Thomas Wilks, 2A Alfred Street, Boar Lane, Leeds.

1861. Low, George, Millgate Iron Works, Newark.
1854. Lynde, James Gascoigne, Town Hall, Manchester.
1856. Mackay, John, Mount Hermon, Drogheda.
1859. Manning, John, Boyne Engine Works, Hunslet, Leeds.
1862. Mansell, Richard Christopher, South Eastern Railway, Carriage Department, Ashford.
1862. Mappin, Frederick Thorpe, Sheaf Works, Sheffield.
1857. March, George, Union Foundry, Leeds.
1856. Markham, Charles, Midland Railway, Derby.
1848. Marshall, Edwin, Britannia Carriage Works, Birmingham.
1862. Marshall, James, Engineer, Seaton Delaval Colliery, near Newcastle-on-Tyne.
1859. Marshall, William Ebenezer, Sun Foundry, Leeds.
1847. Marshall, William Prime, 81 Newhall Street, Birmingham.
1859. Marten, Edward Bindon, Stourbridge Water Works, Stourbridge.
1860. Marten, George Priestley, Messrs. Stothert and Marten, Steam Ship Works, Bristol.
1853. Marten, Henry, Parkfield Iron Works, near Wolverhampton.
1857. Martindale, Capt. Ben Hay, R.E., War Office, Pall Mall, London, S.W.
1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.
1857. Masselin, Armand, 16 Rue Dauphine, Paris.
1853. Mathews, William, Corbyn's Hall Iron Works, near Dudley.
1848. Matthew, John, Messrs. John Penn and Co., Marine Engineers, Greenwich, S.E.
1847. Matthews, William Anthony, Sheaf Works, Sheffield.
1861. May, Robert Charles, 3 Great George Street, Westminster, S.W.
1857. May, Walter, Suffolk Works, Berkley Street, Birmingham.
1860. Mayer, Joseph, Iron Ship Builder, Linz, Austria: (or care of William Seyd, 35 Ely Place, Holborn, London, E.C.)
1859. Maylor, William, East Indian Iron Company, Bypoor: (or care of E. J. Burgess, 8 Austin Friars, London, E.C.)
1847. McClean, John Robinson, 17 Great George Street, Westminster, S.W.
1860. McKenzie, James, Well House Foundry, Leeds.
1859. McKenzie, John, Vulcan Iron Works, Worcester.
1862. McPherson, Hugh, Engineer, Gloucester Gas Works, Gloucester.
1858. Meik, Thomas, Engineer to the River Wear Commissioners, Sunderland.
1857. Menelaus, William, Dowlais Iron Works, Merthyr Tydvil.
1857. Metford, William Ellis, Flook House, Taunton.
1847. Middleton, William, Vulcan Iron Foundry, Summer Lane, Birmingham.
1862. Miers, Francis C., Bohemia House, Chiswick, London, W.
1853. Miller, George Mackey, Great Southern and Western Railway, Dublin.
1862. Millward, John, Union Chambers, High Street, Stourbridge.

1856. Mitchell, Charles, Iron Ship Building Yard, Low Walker, Newcastle-on-Tyne.
 1858. Mitchell, James, Melrose Cottage, Plumstead Common, near Woolwich, S.E.
 1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley.
 1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
 1849. Morrison, Robert, Ouseburn Engine Works, Newcastle-on-Tyne.
 1858. Mountain, Charles George, Suffolk Works, Berkley Street, Birmingham.
 1857. Muntz, George Frederick, French Walls, near Birmingham.
 1856. Muntz, George Henri Marc, Albion Tube Works, Nile Street, Birmingham.
 1859. Murphy, James, Railway Works, Newport, Monmouthshire.
 1858. Murray, Thomas H., Engine Works, Chester-le-Street, near Fence Houses.

 1848. Napier, John, Vulcan Foundry, Glasgow.
 1856. Napier, Robert, Vulcan Foundry, Glasgow.
 1861. Natorp, Gustavus, Messrs. Naylor Vickers and Co., Don Steel Works, Sheffield.
 1861. Naylor, John William, Wellington Foundry, Leeds.
 1858. Naylor, William, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.
 1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
 1856. Newall, James, East Lancashire Railway, Carriage Department, Bury, Lancashire.
 1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
 1858. Nichol, Peter Dale, Locomotive Superintendent, East Indian Railway, Allahabad: (or care of Anthony Nichol, 22 Quay, Newcastle-on-Tyne.)
 1850. Norris, Richard Stuart, 272 Upper Parliament Street, Liverpool.

 1860. Oastler, William, Engineer, Worcester Gas Works, Worcester.
 1847. Owen, William, Messrs. Sandford and Owen, Phoenix Works, Rotherham.

 1859. Paquin, Jean François, Locomotive Superintendent, Madrid Saragossa and Alicante Railways, Madrid.
 1860. Parkin, John, Harvest Lane Steel Works, Sheffield.
 1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton, near Manchester.
 1848. Pearson, John, 1 Manchester Buildings, Old Hall Street, Liverpool.
 1859. Peet, Henry, London and North Western Railway, Locomotive Department, Wolverton.
 1861. Perkins, Loftus, 6 Francis Street, Regent's Square, London, W.C.
 1856. Perring, John Shae, 104 King Street, Manchester.
 1860. Peyton, Edward, Bordesley Works, Birmingham.
 1856. Piggott, George, Birmingham Heath Boiler Works, Birmingham.
 1854. Pilkington, Richard, Jun., Eccleston Hall, near Prescott.
 1859. Pitts, Joseph, Old Foundry, Stanningley, near Leeds.

1859. Platt, John, Hartford Iron Works, Oldham.
 1862. Player, John, Norton, near Stockton-on-Tees.
 1861. Plum, Thomas William, 69 King William Street, London, E.C.
 1856. Pollard, John, Midland Junction Foundry, Leeds.
 1860. Ponsonby, Edward Vincent, Engineer, West Midland Railway, Worcester.
 1852. Porter, John Henderson, Ebro Works, Tividale, near Tipton.
 1861. Porter, Robert, Ebro Works, Tividale, near Tipton.
 1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.
1862. Rake, Alfred Stansfield, Canal Street Works, Manchester.
 1847. Ramsbottom, John, Locomotive Superintendent, London and North Western Railway, Crewe.
 1860. Ransome, Allen, Jun., Messrs. Worssam and Co., King's Road, Chelsea, London, S.W.
 1862. Ransome, Robert James, Orwell Works, Ipswich.
 1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.
 1859. Rennie, George Banks, 39 Wilton Crescent, Belgrave Square, London, S.W.
 1862. Reynolds, Edward, Messrs. Naylor Vickers and Co., Don Steel Works, Sheffield.
 1856. Richards, Josiah, Abersychan Iron Works, Pontypool.
 1862. Richardson, Robert, 26 Great George Street, Westminster, S.W.
 1858. Richardson, Thomas, Hartlepool Iron Works, Hartlepool.
 1859. Richardson, William, Hartford Iron Works, Oldham.
 1848. Robertson, Henry, Shrewsbury and Chester Railway, Shrewsbury.
 1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
 1852. Rofe, Henry, Engineer, Birmingham Water Works, Paradise Street, Birmingham.
1853. Ronayne, Joseph P., 4 Harbour Hill, Queenstown.
 1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Leeds.
 1857. Routledge, William, New Bridge Foundry, Salford, Manchester.
 1860. Rumble, Thomas William, 6 Broad Street Buildings, New Broad Street, London, E.C.
 1847. Russell, John Scott, 20 Great George Street, Westminster, S.W.
1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
 1859. Salt, George, Saltaire, near Bradford, Yorkshire.
 1848. Samuel, James, 26 Great George Street, Westminster, S.W.
 1837. Samuelson, Alexander, 28 Cornhill, London, E.C.
 1837. Samuelson, Martin, Scott Street Foundry, Hull.
 1861. Sanderson, George G., Parkgate Iron Works, Rotherham.
 1860. Schneider, Henry William, Ulverstone Hematite Iron Works, Barrow, near Ulverstone.

1858. Scott, Joseph, Messrs. R. & W. Hawthorn, Forth Banks, Newcastle-on-Tyne.
1848. Scott, Michael, 26 Parliament Street, Westminster, S.W.
1861. Scott, Walter Henry, London and North Western Railway, Locomotive Department, Crewe.
1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.
1850. Shanks, Andrew, 6 Robert Street, Adelphi, London, W.C.
1862. Sharpe, William John, 1 Victoria Street, Westminster, S.W.
1856. Shelley, Charles Percy Bysshe, 21 Parliament Street, Westminster, S.W.
1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.
1859. Shuttleworth, Joseph, Stamp End Works, Lincoln.
1851. Siemens, Charles William, 3 Great George Street, Westminster, S.W.
1862. Siemens, Frederick, 13 Beaufort Road, Edgbaston, Birmingham.
1862. Silvester, John, Messrs. George Salter and Co., Spring Balance Works, Westbromwich.
1862. Simpson, William, Conservative Club, St. James' Street, London, S.W.
1847. Sinclair, Robert, Great Eastern Railway, Stratford, London, E.
1857. Sinclair, Robert Cooper, Atherstone.
1859. Slater, Isaac, Gloucester Wagon Company, Gloucester.
1853. Slaughter, Edward, Avonside Iron Works, Bristol.
1859. Smith, Charles Frederic Stuart, Mining Engineer, Midland Road, Derby.
1854. Smith, George, Wellington Road, Dudley.
1847. Smith, Henry, Spring Hill Works, Birmingham.
1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.
1858. Smith, Isaac, 36 Lancaster Street, Birmingham.
1860. Smith, John, Brass Foundry, Traffic Street, Derby.
1857. Smith, Josiah Timmis, Ulverstone Hematite Iron Works, Barrow, near Ulverstone.
1859. Smith, Matthew, Fazeley Street Wire Mills, Birmingham.
1860. Smith, Richard, The Priory, Dudley.
1857. Smith, William, 19 Salisbury Street, Adelphi, London, W.C.
1857. Snowdon, Thomas, Stockton-on-Tees.
1859. Sokoloff, Capt. Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)
1858. Sørensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)
1859. Spencer, John Frederick, 8 St. Nicholas Buildings, Newcastle-on-Tyne.
1853. Spencer, Thomas, Old Park Works, near Shiffnal.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.
1862. Stableford, William, Oldbury Carriage Works, near Birmingham.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.
1857. Stokes, Lingard, The White House, Newent, near Gloucester.
1862. Strong, Joseph F., Resident Engineer, East Indian Railway, Allahabad.
1861. Sumner, William, 21 Clarence Street, Manchester.
1860. Swindell, James Evers, Parkhead Iron Works, Dudley.
1859. Swinger, Thomas, Victoria Foundry, Litchurch, near Derby.
1861. Tangye, James, Cornwall Works, Clement Street, Birmingham.
1859. Tannett, Thomas, Victoria Foundry, Leeds.
1861. Taylor, George, Clarence Iron Works, Leeds.
1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.
1862. Taylor, John, Jun., Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1857. Thompson, John Taylor, Messrs. R. and W. Hawthorn, Forth Banks, Newcastle-on-Tyne.
1857. Thompson, Robert, Haigh Foundry, near Wigan.
1862. Thompson, William, Spring Garden Engine Works, Newcastle-on-Tyne.
1852. Thomson, George, Crookhay Iron Works, Westbromwich.
1861. Thwaites, Robinson, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1862. Tijou, William, St. Nicholas Works, Thetford.
1861. Tipping, Isaac, H. M. Gun Carriage Manufactory, Madras : (or care of H. Tipping, Bridgewater Foundry, Patricroft, near Manchester.)
1862. Tolmé, Julian Horn, 13 Duke Street, Westminster, S.W.
1857. Tomlinson, Joseph, Jun., Locomotive Superintendent, Taff Vale Railway, Cardiff.
1856. Tosh, George, Locomotive Superintendent, Maryport and Carlisle Railway, Maryport.
1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.
1862. Troward, Charles, Great Northern Railway, Locomotive Department, Doncaster.
1856. Truss, Thomas, Shrewsbury and Chester Railway, Carriage Department, Chester.
1859. Turner, Edwin, Bowling Iron Works, near Bradford, Yorkshire.
1856. Tyler, Capt. Henry Wheatley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.
1862. Upward, Alfred, Engineer, Chartered Gas Company, 146 Goswell Street, London, E.C.

1862. Vavasour, Josiah, 28 Gravel Lane, Southwark, London, S.E.
 1856. Vernon, John, Iron Ship Building Yard, Brunswick Dock, Liverpool.
 1861. Vickers, Thomas Edward, Don Steel Works, Sheffield.
1856. Waddington, John, New Dock Iron Works, Leeds.
 1856. Waddington, Thomas, New Dock Iron Works, Leeds.
 1861. Walker, John G., Netherton Iron Works, near Dudley.
 1847. Walker, Thomas, Patent Shaft Works, Wednesbury.
 1856. Wardle, Charles Wetherell, Boyne Engine Works, Hunslet, Leeds.
 1852. Warham, John R., Iron Works, Burton-on-Trent.
 1862. Watkins, Richard, Messrs. Jackson and Watkins, Canal Iron Works, Millwall, London, E.
 1847. Weallens, William, Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
 1862. Webb, Francis William, London and North Western Railway, Locomotive Department, Crewe.
 1862. Webb, Henry Arthur, Bretwell Hall Iron Works, near Stourbridge.
 1860. Weild, William, Queen's Chambers, Market Street, Manchester.
 1862. Wells, Charles, Moxley Iron Works, near Bilston.
 1862. Westmacott, Percy G. B., Elswick Engine Works, Newcastle-on-Tyne.
 1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston.
 1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.
 1859. Whitham, Joseph, Perseverance Iron Works, Kirkstall Road, Leeds.
 1847. Whitworth, Joseph, Chorlton Street, Manchester.
 1859. Wickham, Henry Wickham, M.P., Low Moor Iron Works, near Bradford, Yorkshire.
 1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.
 1847. Williams, Richard, Patent Shaft Works, Wednesbury.
 1859. Williams, Richard Price, Stocksbridge Iron Works, Deepcar, near Sheffield.
 1856. Wilson, Edward, West Midland Railway, Worcester.
 1858. Wilson, Edward Brown, 36 Parliament Street, Westminster, S.W.
 1859. Wilson, George, Messrs. Cammell and Co., Cyclops Steel Works, Sheffield.
 1852. Wilson, Joseph W., 9 Buckingham Street, Strand, London, W.C.
 1857. Wilson, Robert, Bridgewater Foundry, Patricroft, near Manchester.
 1860. Wilson, William, 27 Duke Street, Westminster, S.W.
 1862. Winby, William Edward, Bombay Baroda and Central Indian Railway ; 10 Liverpool Street, New Broad Street, London, E.C.
 1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.
 1858. Wood, Nicholas, Hetton Hall, Hetton, near Fence Houses.
 1848. Woodhouse, Henry, London and North Western Railway, Stafford.
 1851. Woodhouse, John Thomas, Midland Road, Derby.
 1861. Woodhouse, William Henry, 23 Parliament Street, Westminster, S.W.

1858. Woods, Hamilton, Messrs. Allsopp and Sons, Burton-on-Trent.
 1860. Worssam, Samuel William, King's Road, Chelsea, London, S.W.
 1860. Worthington, Samuel Barton, Engineer, London and North Western Railway, Manchester.
 1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
 1860. Wright, Joseph, Neptune Works, Tipton Green, Dudley.
 1859. Wrigley, Francis, Queen's Chambers, Market Street, Manchester.
 1853. Wymer, Francis W., Tyne and Continental Steam Navigation Company, Newcastle-on-Tyne.
 1861. Yule, William, Baird's Works, St. Petersburg.

HONORARY MEMBERS.

1848. Branson, George, Belmont Row, Birmingham.
 1851. Clare, Thomas Deykin, Carr's Lane, Birmingham.
 1848. Crosby, Samuel, Leek Street, Birmingham.
 1850. Gwyther, Edwin, Belmont Row, Birmingham.
 1857. Hawkes, William, Eagle Foundry, Broad Street, Birmingham.
 1860. Hutchinson, William, West Hartlepool.
 1858. Lawton, Benjamin C., 3 St. Nicholas Buildings, Newcastle-on-Tyne.
 1859. Leather, John Towler, Leventhorpe Hall, near Leeds. (*Life Member.*)
 1860. Manby, Cordy, New Street, Dudley.
 1856. Pettifor, Joseph, Midland Railway, Derby.
 1861. Ratcliff, Charles, Wyddrington, Edgbaston, Birmingham.
 1859. Sherriff, Alexander Clunes, General Manager, West Midland Railway, Worcester.
 1848. Warden, William Marston, Edgbaston Street, Birmingham.
 1858. Waterhouse, Thomas, Claremont Place, Sheffield.
 1862. Whitehead, William, Messrs. Naylor Vickers and Co., Don Steel Works, Sheffield.
 1861. Williamson, Alexander W., Ph. D., University College, Gower Street, London, W.C.

GRADUATES.

1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.
 1861. Middleton, Henry Charles, Vulcan Iron Foundry, Summer Lane, Birmingham.
 1851. Potts, John Thorpe, 150 Camberwell Grove, London, S.

PROCEEDINGS.

30 JANUARY, 1862.

The FIFTEENTH ANNUAL GENERAL MEETING of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 30th January, 1862; JAMES FENTON, Esq., Vice-President, in the Chair.

The CHAIRMAN alluded to the irreparable loss sustained by the nation in the recent death of his Royal Highness the Prince Consort, and moved that the Council be requested to prepare and present an Address of condolence to Her Majesty from the Institution of Mechanical Engineers.

The motion was seconded by Mr. A. B. Cochrane, and passed.

(Copy of the Address presented.)

TO THE QUEEN'S MOST EXCELLENT MAJESTY.

May it please your Majesty,

We, the President and Council of the Institution of Mechanical Engineers, on behalf of ourselves and all the Members of this Institution, humbly approach your Majesty with the assurance of our devoted attachment to your throne and person, and of our respectful sympathy with your Majesty on the mournful occasion of the early death of his Royal Highness the Prince Consort.

The eminent qualities and estimable character of his Royal Highness, and the great benefits derived by the country from his influence and exertions for the development of practical science and industrial art, cause this national bereavement to be deeply deplored as an irreparable loss by all classes of your Majesty's subjects, and especially by the members of all scientific associations.

We earnestly pray that your Majesty and your Royal Family may be supported in this great affliction by the consciousness of the entire devotion and sympathy of all your subjects; and that your Majesty's life may be prolonged for many years in health and happiness, to reign over a faithful and affectionate people.

For the Institution of Mechanical Engineers,

W. G. ARMSTRONG,
President.

The Minutes of the last General Meeting were read and confirmed.
The Secretary then read the following

ANNUAL REPORT OF THE COUNCIL.

1862.

The Council have much pleasure, on this the Fifteenth Anniversary of the Institution, in congratulating the Members on the very satisfactory progress and prosperous condition of the Institution.

The Financial statement of the affairs of the Institution for the year ending 31st December, 1861, shows a balance in the Treasurer's hands of £1420 9s. 5d. after the payment of the accounts due to that date. The Finance Committee have examined and checked the receipts and payments of the Institution for the last year 1861, and report that the following balance sheet rendered by the Treasurer is correct. (*See Balance Sheet appended.*)

The Council report with great satisfaction the continued increase in the number of Members that has taken place during the past year; the total number of Members of all classes for the year being 464, of whom 18 are Honorary Members, and 3 are Graduates.

The following deceases of Members of the Institution have occurred during the past year 1861 :—

WILLIAM D. BURLINSON,	. . .	Sunderland.
JOHN HORRIDGE DEANE,	. . .	Liverpool.
EATON HODGKINSON,	. . .	Manchester.
JOHN LEES,	. . . . .	Ashton-under-Lyne.
JOHN ROSS,	. . . . .	Birmingham.
THOMAS JOHN TAYLOR,	. . .	Newcastle-on-Tyne.

The Council have the pleasure of acknowledging the following Donations to the Library of the Institution during the past year, and expressing their thanks to the donors for the valuable and acceptable additions they have presented. The Council wish to urge on the attention of the Members the important advantage of obtaining a good collection of Engineering Books, Drawings, and Models in the Institution, for the purpose of reference by the Members personally or by correspondence; and they trust this desirable object will be promoted by the Members generally, so that by their united aid it may be efficiently accomplished. Members are requested to present to the Institution copies of their works.

LIST OF DONATIONS TO THE LIBRARY.

- Report of the Committee on the Construction of Submarine Cables; from Capt. Galton, R.E.
- Fourth Report of the Commissioner on the Internal Communications of New South Wales; from Capt. Martindale, R.E.
- Statistical Register of New South Wales; from Capt. Martindale, R.E.
- Treatise on the Steam Engine, by John Bourne; from Mr. James Kennedy.
- Mills and Millwork, by William Fairbairn; from the author.
- Iron, its History and Manufacture, by William Fairbairn; from the author.
- Report of the Commissioner of Patents, United States, 1859.
- The Channel Railway, by James Chalmers; from the author.
- Report of the Manchester Association for the Prevention of Steam Boiler Explosions; from Mr. Lavington E. Fletcher.
- Proceedings of the Royal Institution of Great Britain, from the commencement; from the Institution.
- Proceedings of the Institution of Civil Engineers; from the Institution.
- Report of the British Association for the Advancement of Science; from the Association.
- Transactions of the North of England Institute of Mining Engineers; from the Institute.
- Proceedings of the French Institution of Civil Engineers; from the Institution.
- Journal of the Royal United Service Institution; from the Institution.

Transactions of the Institution of Engineers in Scotland; from the Institution.
 Proceedings of the South Wales Institute of Engineers; from the Institute.
 Transactions of the Royal Scottish Society of Arts; from the Society.
 Report of the Royal Cornwall Polytechnic Society; from the Society.
 Journal of the Society of Arts; from the Society.
 The Engineer; from the Editor.
 The Mechanics' Magazine; from the Editor.
 The Civil Engineer and Architect's Journal; from the Editor.
 The London Journal of Arts; from the Editor.
 The Artizan Journal; from the Editor.
 The Practical Mechanic's Journal; from the Editor.
 The Mining Journal; from the Editor.
 The Railway Record; from the Editor.
 The Steam Shipping Journal; from the Editor.
 Photographs of Steam Engines; from Mr. T. H. Murray.

The Council have great satisfaction in referring to the number of Papers that have been brought before the meetings during the past year, and the practical value and interest of many of the communications, which form a valuable addition to the Proceedings of the Institution. The Council request the special attention of the Members to the importance of their aid and co-operation in carrying out the objects of the Institution and maintaining its advanced position, by contributing papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended, and other subjects advantageous to the Institution.

The following Papers have been read at the meetings during the last year :—

Address of the President, Sir William G. Armstrong.
 Description of the Buda Wrought Iron Lighthouse; by Mr. John H. Porter, of Birmingham.
 On Benson's High Pressure Steam Boiler; by Mr. John James Russell, of Wednesbury.
 Description of a method of Supplying Water to Locomotive Tenders whilst running; by Mr. John Ramsbottom, of Crewe.
 Description of a Self-acting Machine for Spooling Thread; by Mr. William Weild, of Manchester.

- On a new mode of Coking in Ovens, applied to the Staffordshire Slack; by Mr. Alexander B. Cochrane, of Dudley.
- On a Boiler, Engine, and Surface Condenser, for very high pressure steam with great expansion; by Alexander W. Williamson, Ph.D., and Mr. Loftus Perkins, of London.
- On the Manufacture of Steel Rails and Armour Plates; by Mr. John Brown, of Sheffield.
- On the Manufacture of Cast Steel and its Application to constructive purposes; by Mr. Henry Bessemer, of London.
- On the Strength of Steel containing different proportions of Carbon; by Mr. T. Edward Vickers, of Sheffield.
- On the Construction and Erection of Iron Piers and Superstructures for Railway Bridges in alluvial districts; by Lt.-Colonel J. P. Kennedy, of London.
- On Cast Iron Tubbing used in sinking shafts; by Mr. John Brown, of Barnsley.
- Description of a Rivet-Making Machine; by Mr. Charles De Bergue, of Manchester.
- On an application of Giffard's Injector as an Elevator for the Drainage of colliery workings; by Mr. Charles W. Wardle, of Leeds.
- Description of Sellers' Screwing Machine; by Mr. Charles P. Stewart, of Manchester.

The Council have particular pleasure in referring to the great success and interest of the Meeting of the Institution in Sheffield last summer, and in expressing their special thanks to the Local Committee and the Honorary Local Secretary, Mr. T. F. Cashin, for the excellent reception that was given to the Members of the Institution on that occasion; and they look forward with much confidence to the important advantages arising from the continuance of these Meetings in different parts of the country, from the facilities afforded by them for the personal communication of the Members in different districts of the country, and the opportunities of visiting the important Engineering Works that are so liberally thrown open to their inspection on those occasions.

The President, Vice-Presidents, and five of the Members of the Council in rotation, will go out of office this day, according to the rules of the Institution; and the ballot will be taken at the present annual meeting for the election of the Officers and Council for the ensuing year.

INSTITUTION OF MECHANICAL ENGINEERS.

BALANCE SHEET.

For the year ending 31st December, 1861.

<i>Cr.</i>	£	s.	d.	<i>Dr.</i>	£	s.	d.
By Balance 31st December, 1860.	1109	2	11	To Printing and Engraving Reports of } Proceedings	368	11	0
" Subscriptions from 24 Members in arrear	72	0	0	Less Authors' copies of papers, repaid	18	19	0
" ditto from 389 Members for 1861	1167	0	0	" Stationery and Printing	49	7	10
" ditto from 3 Graduates for 1861	6	0	0	" Office Expenses and Petty Disbursements . . .	36	5	2
" ditto from 3 Members in advance for 1862 . . .	9	0	0	" Expenses of Meetings	21	5	6
" Entrance Fees from 49 New Members	98	0	0	" Fittings and Repairs	3	17	2
" ditto from 1 New Graduate	1	0	0	" Travelling Expenses	12	10	5
" Sale of Extra Reports	4	8	0	" Parcels	2	17	8
" Interest from Bank	34	3	0	" Postages	39	16	3
				" Salaries	450	0	0
				" Rent and Taxes	114	12	6
				" Balance 31st December, 1861.	1420	9	5
					£2500	13	11

(Signed) SAMPSON LLOYD, } Finance Committee.
WALTER MAY, }

30th January, 1862.

SUBJECTS FOR PAPERS.

STEAM ENGINE BOILERS, particulars of construction—form and extent of heating surface—relative value of radiant surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—pressure gauges—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low pressure and high pressure—steel boilers—incrustation of boilers, and means of prevention—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed water—mode of feeding—circulation of water.

STEAM ENGINES—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—injection and surface condensers—air pumps—governors—valves, bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

PUMPING ENGINES, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—construction of pumps—plunger pumps—bucket pumps—particular details of different valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.

BLAST ENGINES, best kind of engine—size of steam cylinder, strokes per minute, and horse power—details of boilers—size of blowing cylinder, and strokes per minute—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from air main and steam cylinder.

MARINE ENGINES, power of engines in proportion to tonnage—different constructions of engines, double-cylinder engines, trunk engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—governors and storm-governors.

ROTARY ENGINES, particulars of construction and practical application—details of results of working.

LOCOMOTIVE ENGINES, particulars of construction, details of experiments, and results of working—consumption of fuel—use of coal—consumption of smoke—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast pipe—construction of pistons, valve gear, expansion gear, &c.—indicator diagrams—expenses of working and repairs—means of supplying water to tenders.

AGRICULTURAL ENGINES, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars of performance and cost of work done.

CALORIC ENGINES—engines worked by Gas, or explosive compounds—Electromagnetic engines—particulars and results.

HYDRAULIC ENGINES, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

WATER WHEELS, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy.

WIND MILLS, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

CORN MILLS, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—advantages of regularity of motion.

SUGAR MILLS, particulars of construction and working—results of the application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

OIL MILLS, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

COTTON MILLS, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

CALICO-PRINTING AND BLEACHING MACHINERY, particulars of improvements.

WOOL MACHINERY, carding, combing, roving, spinning, &c.

FLAX MACHINERY, manufacture of flax and other fibrous materials, both in the natural length of staple and when cut.

SAW MILLS, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

WOOD-WORKING MACHINES, morticing, planing, rounding, and surfacing—copying machinery.

LATHES, PLANING, BORING, DRILLING, AND SLOTTING MACHINES, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders.

STEAM HAMMERS, improvements in construction and application—friction hammers—air hammers.

RIVETTING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—comparative strength of drilled and punched plates—rivet-making machines.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

PAPER-MAKING AND PAPER-CUTTING MACHINES, new materials and results.

PRINTING MACHINES, particulars of improvements, &c.

WATER PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

AIR PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

HYDRAULIC PRESSES, facts relating to the best construction, means of working, and application—economical limit of pressure.

ROTARY AND CENTRIFUGAL PUMPS, ditto ditto ditto

FIRE ENGINES, hand and steam, ditto ditto ditto

SLUICES AND SLUICE COCKS, worked by hand or hydraulic power, ditto

CRANES, steam cranes, hydraulic cranes, pneumatic cranes, travelling cranes.

LIFTS for raising railway wagons—hoists for warehouses—safety apparatus.

TOOTHED WHEELS, best construction and form of teeth—results of working—power transmitted—method of moulding—strength of iron and wood teeth.

DRIVING BELTS AND STRAPS, best make and material, leather, gutta percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

DYNAMOMETERS, construction, application, and results of working.

DECIMAL MEASUREMENT—application of decimal system of measurement to mechanical engineering work—drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

STRENGTH OF MATERIALS, facts relating to experiments, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

DURABILITY OF TIMBER of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

CORROSION OF METALS by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature, and preventives.

ALLOYS OF METALS, facts relating to different alloys.

FRICTION OF VARIOUS BODIES, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

IRON ROOFS, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast iron, wrought iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

FIRE-PROOF BUILDINGS, particulars of construction—most efficient plan—results of trials.

CHIMNEY STACKS of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

BRICKS, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry clay bricks—machines for brick making—burning of bricks.

GAS WORKS, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure.

WATER WORKS, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes, and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—water meters, construction and working.

WELL SINKING, AND ARTESIAN WELLS, facts relating to—boring tools, construction and mode of using.

TUNNELLING MACHINES, particulars of construction and results of working.

COFFER DAMS AND PILING, facts relating to the construction—cast iron sheet piling.

PIERS, fixed and floating, and pontoons, ditto ditto

PILE DRIVING APPARATUS, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles.

DREDGING MACHINES, particulars of improvements—application of dredging machines—power required and work done.

DIVING BELLS AND DIVING DRESSES, facts relating to the best construction.

LIGHTHOUSES, cast iron and wrought iron, ditto ditto

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—underground conveyance—mode of breaking, pulverising, and sifting various descriptions of ores.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

BLAST FURNACES, consumption of fuel in different kinds—burden, make, and quality of metal—pressure of blast—horse power required—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working

- of hot blast ovens—pyrometers—means and results of application of waste gas from close-topped and open-topped furnaces.
- PUDDLING FURNACES, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.
- HEATING FURNACES, best construction—consumption of fuel, and heat obtained.
- CONVERTING FURNACES, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.
- SMITHS' FORGES, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.
- SMITHS' FANS and FANS generally, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains.
- COKE and CHARCOAL, particulars of the best mode of making, and construction of ovens, &c.—open coking—mixtures of coal slack and other materials—evaporative power of different varieties.
- RAILWAYS, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.
- SWITCHES AND CROSSINGS, particulars of improvements, and results of working.
- TURNABLES, particulars of various constructions and improvements—engine turntables.
- SIGNALS for stations and trains, and self-acting signals.
- ELECTRIC TELEGRAPHS, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying.
- RAILWAY CARRIAGES AND WAGONS, details of construction—proportion of dead weight.
- BREAKS for carriages and wagons, best construction—self-acting breaks—continuous breaks.
- BUFFERS for carriages, &c., and station buffers—different constructions and materials.
- COUPLINGS for carriages and wagons—safety couplings.
- SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.
- RAILWAY WHEELS, wrought iron, cast iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of solid wrought iron wheels.
- RAILWAY AXLES, best description, form, material, and mode of manufacture.
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The communications should be written on foolscap paper, on one side only of each page, leaving a clear margin on the left side for binding, and they should be written in the third person. The drawings illustrating the paper should be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper; or enlarged diagrams should be added for the illustration of any particular portions: the scale of each drawing to be marked upon it.

MEMOIRS
OF MEMBERS DECEASED IN 1861.

WILLIAM DAVIE BURLINSON was born at Durham in 1802; and after serving his time with Messrs. John Burlinson and Co., engineers and millwrights, Sunderland, became a member of the firm in 1830, in which he took an active part. He erected machinery for the shipment of coals at several sea ports, his father having been the inventor of this description of machinery; and he gave great attention to the manufacture of machinery for making hemp and wire ropes, including the machines for making the Atlantic submarine telegraph cable. His health had been declining for upwards of three years previous to his death, which took place on 4 September 1861, at the age of fifty-nine. He was elected a Member of the Institution in 1858.

JOHN HORRIDGE DEANE was born at Liverpool in 1828, and after serving his time with Messrs. Bury Curtis and Kennedy of that town was appointed in 1854 locomotive superintendent of the Barcelona and Granollers Railway in Spain, and afterwards general manager of the line, until 1859, when he received an engineering appointment in Russia; but he was obliged to return home early in 1860 in consequence of declining health, and died on 10 August 1861 at the early age of thirty-three, after an illness of 18 months. He was elected a Member of the Institution in 1857.

EATON HODGKINSON was born in February 1789 at Anderton near Northwich, Cheshire, where he received his first education at the grammar school. He was originally intended for the church; but his father having died when he was only six years old, he commenced his career as a farmer, to aid his widowed mother in carrying on his

father's business. Neither farming nor the church were however suited to his talents, and at the age of twenty-one he removed with his mother to Salford, Manchester, where they maintained themselves by keeping a shop, whilst he had the advantages of scientific instruction and society, and devoted his spare hours to the study of mathematics and mechanical science, as one of Dr. Dalton's private pupils. At the age of thirty-three, he produced his first scientific work, an essay on the Transverse Strain and Strength of Materials, which was followed by a series of papers on the subject of Suspension Bridges read by him to the Manchester Philosophical Society in 1828 to 1830, his attention having been called to this subject by the erection and failure of a suspension bridge at Broughton near Manchester. In 1833 he commenced that remarkable series of papers and researches on the strength and strains of materials, more especially of Iron, by which he became so eminently distinguished and made so important an addition to the scientific knowledge at the disposal of engineers. In these researches he seems only to have resumed the subject of his earliest paper in 1822, which he may be considered to have completed when in 1857 he received the medal of the Royal Society and in 1861 became Vice-President of the British Association.

The great subject that Eaton Hodgkinson devoted himself to—the investigation of the nature and properties of iron—he followed up with an assiduity of research, a philosophical method, and a clear and strong sagacity, that enabled him to accomplish results which have been of the greatest practical importance in the various and extensive applications of iron, and have effected a complete revolution in practice with that metal, laying all branches of engineering under a great debt of gratitude to him. Before his investigations the mechanical nature and the relative value of cast iron and wrought iron were little understood; and neither the practical value of their resistance to strains, nor the true form and distribution of material for obtaining the best application of their strength to mechanical use, were known: wrought iron was not trusted or used so much as it deserved, whilst cast iron was unduly relied on and inefficiently applied. The section of cast iron girders previously in universal use was an **I** shape, with nearly equal flanges at top and bottom; but

Hodgkinson showed that the resistance of cast iron to fracture by compression being about five times its resistance to tension, the upper flange acting by compression should have only one fifth of the area of the bottom flange in tension, in order to be equal in strength and give the maximum strength of girder with the minimum weight of material, the section of the girder being therefore somewhat of a **I** shape: a great saving in the weight of material required was thereby effected. He showed also the true action of the vertical web of the girder in preserving the top and bottom flanges in their relative positions, and ascertained the extent to which its thickness should be diminished, whereby the weight of material was still further reduced.

In the form and calculation of cast iron columns Eaton Hodgkinson also established some remarkable facts by a series of experiments on the force necessary to crush the column, which he found to be regular: he proved that the bearing strength was increased by enlarging the column in the middle, and also by making the ends flat instead of rounded; while it was diminished by adding to the height of the column beyond a certain point. His formulæ for the calculation of solid and hollow columns, deduced from these experiments, have become the standards in general use. In his investigation of the best form and proportions for wrought iron columns and beams, he showed how the inferior resistance to compression of wrought iron as compared with cast iron could be compensated for by correct distribution of the material, removing the previous practical objections to wrought iron for large structures, and leading to the gradual displacement of cast iron by the more safe and reliable material, wrought iron, thereby affording facilities for overcoming engineering difficulties previously almost insurmountable. He was also engaged in important investigations into the application of iron to railway structures, and the relative values of hot and cold-blast iron, in connexion with a Royal Commission and a committee of the British Association.

Eaton Hodgkinson was eminently a self-made and self-educated man. Deprived in early life of the benefits of a complete education, he devoted himself earnestly to business for the support of his family, and afterwards for the purchase of an honourable leisure, which he

employed first in the completion of his own education, next in association with eminent men of science in Manchester, and finally in the advancement of mechanical science and public researches into various important branches of the subject. From his humble origin he raised himself by his exertions and talents to be successively Member of the Philosophical Society of Manchester, Fellow of the Royal Society, Vice-President of the British Association, and Professor in University College, London: a bright example that the humblest occupation need not derogate from the dignity of personal character, nor interfere with the accomplishment of a brilliant career of public usefulness and high distinction. The secret of his success was undoubtedly his earnestness and singleness of purpose; whatever investigation he undertook he determined to get thoroughly to the bottom of the subject; and held that to understand part of a subject completely, it was requisite to master the whole. He was elected an Honorary Life Member of this Institution in 1849, and died on 18 June 1861 at the age of seventy-two.

JOHN LEES was born at Park Bridge in 1827, and as the active member for ten years in the firm of Messrs. H. Lees and Sons, of Park Bridge Iron Works, Ashton-under-Lyne, was engaged principally in roller making for the use of the cotton spinning districts, in which he introduced several improvements in machines for the manufacture of rollers, &c. He became a Member of the Institution in 1857, and died on 8 October 1861, after a short illness, at the age of thirty-four.

JOHN ROSS was born at Perth in 1812, his father being a stone mason; he was apprenticed to a coach maker at Perth, and subsequently worked at Edinburgh. In 1845 he became foreman to Mr. Thomas Brown, carriage builder, at Birmingham, in whose works he had been for about two years previously; and in 1846 he became manager at Messrs. Brown Marshalls and Co.'s Railway Carriage Works at Birmingham. He was a Member of the Institution from 1853 to the time of his death, which occurred on 22 January 1861, in the forty-ninth year of his age.

THOMAS JOHN TAYLOR, of Earsdon near Newcastle-on-Tyne, was born in 1810 at Shilbottle near Alnwick, and after receiving a liberal education, which he finished at the university of Edinburgh, was brought up under his uncle, Mr. Hugh Taylor, as a colliery viewer, having the care first of some smaller collieries, and afterwards of Haswell Colliery in the county of Durham, a colliery of great extent and importance. He subsequently succeeded his uncle as mining engineer to the Duke of Northumberland, and acted in the same capacity also for the collieries of Lord Hastings and Col. Towneley. He attained a position of great eminence as a mining engineer, and wrote frequently upon subjects connected with mining and the coal trade. In 1843 he published an historical account of coal mining as practised in the North of England, and in 1859 read a paper at this Institution on the progressive application of machinery to mining purposes, having been elected a Member of the Institution in 1858 : his principal work was a treatise on the improvement of the river Tyne, as a great shipping port for coal, giving his views also on the improvement and management of rivers and tidal harbours generally. The last mining project on which he was occupied at the time of his death was the organisation of a comprehensive system for the combined drainage of the whole coal basin of the Tyne, east of Newcastle. His death occurred on 2 April 1861, in the fifty-first year of his age, after a very short illness originating in a violent cold.

The CHAIRMAN remarked that the successful position of the Institution shown by the Report of the Council was highly gratifying and encouraging, and he moved that the Report be received and adopted, which was passed. He announced that the Annual Special Meeting of the Institution would be held in London in the ensuing summer, when they would no doubt have the presence of many engineers from the continent who would be in London on the occasion of the International Exhibition; and he hoped all the Members would do their best to render the meeting thoroughly successful.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following Officers and Members of Council were duly elected for the ensuing year:—

PRESIDENT.

SIR WILLIAM G. ARMSTRONG, . Newcastle-on-Tyne.

VICE-PRESIDENTS.

ALEXANDER B. COCHRANE, . Dudley.

JAMES FENTON, Low Moor.

HENRY MAUDSLAY, London.

JOHN PENN, London.

JOHN RAMSBOTTOM, Crewe.

JOSEPH WHITWORTH, Manchester.

COUNCIL.

ALEXANDER ALLAN, Perth.

GEORGE HARRISON, Birkenhead.

THOMAS HAWKSLEY, London.

EDWARD JONES, Wednesbury.

CHARLES P. STEWART, Manchester.

Members of Council remaining in office.

JOHN ANDERSON, Woolwich.

CHARLES F. BEYER, Manchester.

EDWARD A. COWPER, London.

JOHN FERNIE, Derby.

ROBERT HAWTHORN, Newcastle-on-Tyne.

JAMES KITSON, Leeds.

SAMPSON LLOYD, Wednesbury.

WALTER MAY, Birmingham.

C. WILLIAM SIEMENS,	London.
WILLIAM WEALLENS,	Newcastle-on-Tyne.
TREASURER.	
HENRY EDMUNDS,	Birmingham.
SECRETARY.	
WILLIAM P. MARSHALL,	Birmingham.

The following New Members were also elected :—

MEMBERS.

WILLIAM DEAKIN,	Willenhall.
JOHN ELDER,	Glasgow.
MICHAEL HUNTER, JUN.,	Sheffield.
JOHN LOXTON,	Bilston.
JAMES MARSHALL,	Scaton Delaval.
JOHN PLAYER,	Stockton-on-Tees.
ROBERT JAMES RANSOME,	Ipswich.
WILLIAM JOHN SHARPE,	London.
FREDERICK SIEMENS,	London.
WILLIAM STABLEFORD,	Oldbury.
WILLIAM TIJOU,	London.
WILLIAM EDWARD WINBY,	London.

The following paper was then read :—

ON A REGENERATIVE GAS FURNACE,
AS APPLIED TO GLASSHOUSES, PUDDLING, HEATING,
ETC.

BY MR. C. WILLIAM SIEMENS, OF LONDON.

The arrangement of furnaces about to be described is applicable with the greatest advantage in cases where great heat has to be maintained: as in melting and refining glass, steel, and metallic ores, in puddling and welding iron, and in heating gas and zinc retorts, &c. The fuel employed, which may be of very inferior description, is separately converted into a crude gas, which in being conducted to the furnace has its naturally low heating power greatly increased by being heated to nearly the high temperature of the furnace itself, ranging to above 3000° Fahr.; undergoing at the same time certain chemical changes whereby the heat developed in its subsequent combustion is increased. The heating effect produced is still further augmented by the air necessary for combustion being also heated separately to the same high degree of temperature, before mixing with the heated gas in the combustion chamber or furnace; and the latter is thus filled with a pure and gentle flame of equal intensity throughout the whole chamber. The heat imparted to the gas and air before mixing is obtained from the products of combustion, which after leaving the furnace are reduced to a temperature frequently not exceeding 250° Fahr. on reaching the chimney, whereby great economy in fuel is produced, with other advantages.

The transfer of heat from the products of combustion to the air and gas entering the furnace is effected by means of Regenerators, the principle of which has been recognised to some extent since the early part of the present century, but has not hitherto been carried out in any useful application in the arts, unless the respirator invented by Dr. Jeffreys be so considered. The discovery of this principle is

ascribed to Rev. Mr. Stirling of Dundee, who in conjunction with his brother, James Stirling, attempted as early as the year 1817 to apply it to the construction of a hot air engine: their engine did not however succeed, nor did Capt. Ericsson's later attempts in the same direction lead to more satisfactory results. The economical principle of the regenerator having attracted the writer's attention in 1846, he constructed in the following year an engine in which superheated steam was used in conjunction with the regenerator: many practical difficulties however prevented a realisation of the success which theory and experiments appeared to promise; but it is gratifying to find that one principle then adopted, that of superheating the steam, has since received the sanction of an extended application.

The employment of regenerators for getting up a high degree of heat in furnaces was suggested in 1857 by the writer's brother, Mr. Frederick Siemens, and has since been worked out by them conjointly through the several stages of progressive improvement. The results obtained by the earlier applications of the principle were communicated by the writer in a paper read at a former meeting of this Institution (see Proceedings Inst. M.E., 1857, page 103): and two or three of the furnaces then described, employed for heating bars of steel, remain still in operation. In attempting however to apply the principle to puddling and other larger furnaces, serious practical difficulties arose, which for a considerable time frustrated all efforts; until by adopting the plan of volatilising the solid fuel in the first instance, and employing it entirely in a gaseous form for heating purposes, practical results were at length attained surpassing even the sanguine expectations previously formed.

In the early form of the regenerative heating furnace, which has been in continuous work during the last three years for heating bars of steel at Messrs. Marriott and Atkinson's Steel Works, Sheffield, and also at the Broughton Copper Works, Manchester, there is a single fireplace containing a ridge of fuel fed from the top; and two heating chambers, in which the bars of metal to be heated are laid, with a regenerator at the end of each chamber, by which the waste heat passing off from the furnace is intercepted on its way to the

chimney, and transferred to the air entering the furnace. Each regenerator is composed of a mass of open firebricks, exposing a large surface for the absorption of heat, through which the products of combustion are made to pass from the furnace, and are thus gradually deprived of nearly all their heat previous to escaping into the chimney: the end of the regenerator nearest the furnace becomes gradually heated to nearly the temperature of the furnace itself, while the other end next the chimney remains comparatively cool. The direction of the draught being now reversed by means of a valve, the air entering the furnace is made to pass through the heated regenerator in the contrary direction, encountering first the cooler portions of the brickwork, and acquiring successive additions of heat in passing through the regenerator, until it issues into the first chamber of the furnace at a very high temperature, and traversing the ridge of fuel produces a flame which fills the second heating chamber; whence the products of combustion passing through the second cold regenerator deposit their heat successively in the inverse manner, reaching the chimney comparatively cool. By thus alternating the current through the two regenerators, a high degree of temperature is maintained constantly in the furnace. This arrangement of furnace is evidently applicable only in exceptional cases where two chambers are to be heated alternately, nor does it admit of being carried out upon a large scale.

In heating a single chamber the expedient was resorted to of providing two fireplaces to be traversed in succession by the heated air, with the heating chamber placed between, as in the furnace shown in the drawings accompanying the previous paper (Proceedings Inst. M. E., 1857, Plate 118). Here the difficulty arose that the air, the oxygen of which was already combined with carbon (forming carbonic acid) in traversing the first fireplace, took up a second equivalent of carbon (forming carbonic oxide) in traversing the second, so that the fuel of the second fire was consumed to no purpose. In order to diminish this loss and also avoid impairing the draught by a double resistance, the ridges of fuel were discontinued and the coal was fed into the furnace from the sides, resting on a solid hearth, to be there volatilised by the heated air passing over it. By frequently stirring the

first fire its combustion was favoured until the current was reversed, when it was left undisturbed until the next change, and so on alternately. It was found very difficult however to maintain an active and uniform combustion and to burn the purely carbonaceous substance that was left in the fireplace after the gaseous portion of the fuel had been volatilised; and it had frequently to be raked out in order to make room for fresh gaseous fuel. This circumstance led to the first step towards the employment of fuel in the form of gas, by providing a small grate below the heap of fuel, through which a gentle current of air was allowed to enter, forming carbonic oxide, which afterwards further combined with oxygen on meeting with the hot current of air entering the furnace from the regenerator. The two fireplaces of alternating activity were however attended with considerable practical inconvenience: the furnacemen in particular disliked the idea of attending two fireplaces instead of one, and being little interested in the saving of fuel, took no pains to work the furnace in a satisfactory manner.

It therefore became necessary to devise a plan of heating a single chamber continuously by one fireplace, in combination with the alternate reversal of currents through the regenerators, but without reversing the direction of the flame. This was accomplished by means of double reversing valves, and was practically carried out in a puddling furnace that worked for a considerable length of time at the ironworks of Messrs. R. and W. Johnson near Manchester. The two regenerators were placed longitudinally side by side, with a flue between, underneath the puddling chamber, and the fireplace was put at one end of the puddling chamber, as in an ordinary puddling furnace, and fed with fuel from above. The heated air from the first regenerator was brought up at the back of the fireplace, and meeting there with the fuel produced the required flame in the puddling chamber; whence the products of combustion passed down at the end of the chamber, and were carried back along the flue below to the hot end of the second regenerator, through which they made their way to the chimney. For reversing the currents through the regenerators two valves were needed, connected by a lever, one at the hot end of the regenerators near the fire, and the other at the cool end next the chimney; whereby the

heated air was made to enter the fireplace by the same passage as previously, and the direction of the flame through the puddling chamber was not changed. By this arrangement the regenerative furnace was assimilated as nearly as could be to an ordinary puddling furnace in form and mode of working. The few furnaces constructed in this manner produced a great heat with little more than one half the consumption of fuel of ordinary furnaces in doing the same amount of work. A considerable saving of iron was also effected in puddling, owing to the absence of strong cutting draughts, a mild draught being found sufficient to produce the necessary heat. There still remained drawbacks however which prevented an extensive application of this form of furnace: the fire required frequent attention, and it was difficult to maintain a uniform volume of flame in the furnace; the reversing valve at the hot end of the regenerators was moreover liable to get out of order, and the furnace was costly to erect.

The most important step in the development of the regenerative furnace has been the complete separation of the fireplace or gas producer from the heating chamber or furnace itself. When a uniform and sufficient supply of combustible gas is ensured, it can evidently be heated just like the air, by being passed through a separate regenerator before reaching the furnace, whereby its heating power is greatly increased. The difficulty of maintaining a uniform flame in the furnace is thereby certainly removed, and there is no longer any necessity for keeping the flame always in the same direction through the furnace, since the gas can be introduced with equal facility at each end of the heating chamber in turn, and the periodical change of direction of the flame through the furnace tends only to make the heat more uniform throughout: whereas in the previous plan of employing solid fuel for heating in the furnace, the relative position of the fireplace and heating chamber being fixed and unchangeable required the direction of the flame to be kept always the same, unaltered by the reversal of currents through the regenerators. The new plan of a separate gas producer has now been successfully carried out in practice, and there are already a considerable number of the regenerative gas furnaces in satisfactory operation in this country and on the continent, applied to

glasshouses, iron furnaces, &c. In the neighbourhood of Birmingham, at Messrs. Lloyd and Summerfield's Glass Works, a flint glass furnace constructed upon this plan has now been in continuous operation for nearly twelve months, and affords a good opportunity for ascertaining the consumption of fuel of the regenerative furnace as compared with the previous furnace performing the same work. At the Glass Works of Messrs. Chance Brothers and Co. near Birmingham, the regenerative gas furnace has been under trial for the same length of time, and has latterly been adopted for the various purposes in crown and sheet glass making upon a very large scale. Messrs. James Russell and Sons, Crown Tube Works, Wednesbury, are also applying the furnace to the delicate operation of welding iron tubes, and in a short time will probably employ no solid fuel for any furnaces at their works. Another flint glass furnace erected by Messrs. Osler in Birmingham, and several puddling furnaces erected by Messrs. Gibbs Brothers at Deepfields, and by Mr. Richard Smith at the Round Oak Iron Works, are amongst the latest applications of the regenerative gas furnace, the designs having in all cases been furnished by the writer and carried out under his brother's immediate superintendence.

The Gas Producer is shown in Figs. 1, 2, and 3, Plates 1 and 2 : Fig. 1 is a longitudinal section, Fig. 2 a front elevation and transverse section at the front, and Fig. 3 a transverse section at the back. The producers are entirely separate from the furnace where the heat is required, and are made sufficient in number and capacity to supply several furnaces. The fuel, which may be of the poorest description, such as slack, coke dust, lignite, or peat, is supplied at intervals of from 6 to 8 hours through the covered holes A, Figs. 1 and 2, and descends gradually on the inclined plane B, which is set at an inclination of from 45° to 60° according to the nature of the fuel used. The upper portion of the incline B is made solid, being formed of iron plates covered with firebrick ; but the lower portion C is an open grate formed of horizontal flat steps. At the foot of the grate C is a covered water trough D, filled with water up to a constant level from the small feeding cistern E, supplied by a water pipe with a ball tap. The large opening under the water trough is convenient for drawing out clinkers, which generally collect at that point. The small stoppered

holes F F at the front and G G at the top of the producer are provided to allow of putting in an iron bar occasionally to break up the mass of fuel and detach clinkers from the side walls. Each producer is made large enough to hold about 10 tons of fuel in a low incandescent state, and is capable of converting about 2 tons of it daily into a combustible gas, which passes off through the opening H into the main gas flue leading to the furnaces.

The action of the gas producer in working is as follows: the fuel descending slowly on the solid portion B of the inclined plane, Plate 1, becomes heated and parts with its volatile constituents, the hydro-carbon gases, water, ammonia, and some carbonic acid, which are the same as would be evolved from it in a gas retort. There now remains from 60 to 70 per cent. of purely carbonaceous matter to be disposed of, which is accomplished by the slow current of air entering through the grate C, producing regular combustion immediately upon the grate; but the carbonic acid thereby produced, having to pass slowly on through a layer of incandescent fuel from 3 to 4 feet thick, takes up another equivalent of carbon, and the carbonic oxide thus formed passes off with the other combustible gases to the furnace. For every cubic foot of combustible carbonic oxide thus produced, taking the atmosphere to consist of 1-5th part by volume of oxygen and 4-5ths of nitrogen, two cubic feet of incombustible nitrogen pass also through the grate, tending greatly to diminish the richness or heating power of the gas. Not all the carbonaceous portion of the fuel is however volatilised on such disadvantageous terms: for the water trough D at the foot of the grate, absorbing the spare heat from the fire, emits steam through the small holes I under the lid; and each cubic foot of steam in traversing the layer of from 3 to 4 feet of incandescent fuel is decomposed into a mixture consisting of one cubic foot of hydrogen and nearly an equal volume of carbonic oxide, with a variable small proportion of carbonic acid. Thus one cubic foot of steam yields as much inflammable gas as five cubic feet of atmospheric air; but the one operation is dependent upon the other, inasmuch as the passage of air through the fire is attended with the generation of heat, whereas the production of the water gases, as well as the evolution of the hydro-carbons, is carried on at the expense of heat. The generation

of steam in the water trough being dependent on the amount of heat in the fire, regulates itself naturally to the requirements; and the total production of combustible gases varies with the admission of air. And since the admission of air into the grate depends in its turn upon the withdrawal of the gases evolved in the producer, the production of the gases is entirely regulated by the demand for them. The production of gas may even be arrested entirely for 12 hours without deranging the producer, which will begin work again as soon as the gas valve of the furnace is reopened; since the mass of fuel and brickwork retain sufficient heat to keep up a dull red heat in the producer during that interval. The gas is however of a more uniform quality when there is a continuous demand for it, and for this reason it is best to supply several furnaces from one set of producers, so as to keep the producers constantly at work. The opening H leading from each producer into the main gas flue can be closed by inserting a damper from above, as shown in Fig. 1, in case any one of the producers is required to be stopped for repairs or because part of the furnaces supplied are out of work.

It is important that the main gas flue leading to the furnaces should contain an excess of pressure however slight above the atmosphere, in order to prevent any inward draughts of air through crevices, which would produce a partial combustion of the gas and diminish its heating power in the furnace, besides causing a deposit of soot in the flues. It is therefore necessary to deliver the gas into the furnace without depending upon a chimney draught for that purpose. This could easily be accomplished if the gas producers were placed at a lower level than the furnaces, but as that is generally impossible, the following plan has been adopted. The mixture of gases on leaving the producers has a temperature ranging between 300° and 400° Fahr., which must under all circumstances be sacrificed, since it makes no difference to the result at what temperature the gas to be heated enters the regenerators, the final temperature being in all cases very nearly that of the heated chamber of the furnace or say 2500° Fahr. The initial heat of the gas is therefore made available for producing a plenum of pressure by making the gas rise about 20 feet above the producers, then carrying it horizontally 20 or 30 feet through the wrought iron tube J, Plate 1, and

letting it again descend to the furnace, as shown by the arrows in Fig. 1. The horizontal tube J being exposed to the atmosphere causes the gas to lose from 100° to 150° of temperature, which increases its density from 15 to 20 per cent. and gives a preponderating weight to that extent to the descending column, urging it forwards into the furnace.

The application of the regenerative gas furnace as a Plate Glass Melting Furnace is shown in Plates 3 to 6, which represent a melting furnace now in course of erection at the British Plate Glass Works near St. Helen's. This furnace does not differ materially from the regenerative gas furnaces previously erected and at work at Messrs. Chance's and Messrs. Lloyd and Summerfield's, but is selected in preference because it is the most improved in details of construction. Plate 3 shows a longitudinal section of the furnace, Plate 4 a transverse section, and Plate 5 a sectional plan above and below the bed or "siege" as it is termed of the furnace. Figs. 7, 8, and 9, Plate 6, show the detail of the gas and air valves.

The heating chamber A of the furnace, Figs. 4 and 5, contains twelve glass pots B, which are got out through the side doors when the glass is ready for casting upon the moulding table. Underneath are placed transversely the four regenerators C C, composed of open firebricks built up on a grating, which are arched over at the top and support the bed or siege D of the furnace. The regenerators work in pairs, the two under the right hand end of the siege communicating with that end of the heating chamber, while the other two communicate with the opposite end, as shown in Fig. 4. The gas enters the chamber through the three passages E, Figs. 5 and 6, and the air through the two intermediate passages F, whereby they are kept entirely separate up to the moment of entering the furnace, but are then able immediately to mingle intimately, producing at once an intense and uniform flame in the heating chamber. The siege D is built of firebrick, with a number of transverse channels, shown black in Figs. 4 and 8, through which the cold entering air is made to pass on its way into the air flue G, as shown by the arrows in Fig. 5; by this means the siege is kept comparatively cool, so that no fluid glass can pass through crevices into the regenerators. Any melted glass

that may fall from the heating chamber through the apertures at the ends of the sieve does not get into the regenerators, but falls into the pockets M, Fig. 4, whence it can be removed through the opening at the bottom. The passage N, Fig. 5, by which the air enters, affords the means of getting at the regenerators through an opening at the end of each.

From the air flue G, Fig. 8, the entering air is directed by the reversing valve H into the air regenerator, as shown by the arrows, and there becomes heated ready for entering the furnace; at the same time the gas entering from the gas flue I, Fig. 7, is directed by the reversing valve J into the gas regenerator, where it becomes heated to the same temperature as the air. Similarly the products of combustion on leaving the opposite end of the furnace pass down through the second pair of regenerators, as shown by the arrows in Fig. 4, and after being here deprived of their heat are directed by the reversing valves H and J into the chimney flue K. When the second pair of regenerators have become considerably heated by the passage of the hot products of combustion, and the first pair correspondingly cooled by the entering air and gas, the valves H and J are reversed by the hand levers, as shown dotted in Figs. 7 and 8, causing the currents to pass through the regenerators and the heating chamber in the contrary direction, whereby the hot pair of regenerators are now made use of for heating the gas and air entering the furnace, while the cool pair abstract the heat from the products of combustion escaping from the furnace. The supply of air and gas to the furnace is regulated by the adjustable stop valves L, whereby the nature and volume of the flame in the furnace may be varied at pleasure; whilst the chimney damper is used to regulate the amount of pressure in the furnace in relation to the atmosphere, so as to allow the opening of working holes.

The construction of furnace above described may be varied in many ways to suit local circumstances. The regenerators are in some instances not placed immediately under but at the side of the furnace; but it is important that they should always be placed at a lower level than the furnace, in order that the air and gas may rise naturally into the heating chamber, forming there a plenum of pressure.

Plates 7, 8, and 9 show the application of the regenerative gas furnace as a Round Flint Glass Furnace. Plates 7 and 8 show vertical sections of the furnace taken at right angles to each other, and Plate 9 a sectional plan above and below the siege. The round form of furnace is found convenient in flint glass houses, affording the greatest amount of accommodation to the glass blowers. The four regenerators C are here arranged below the siege as before, and the air and gas from the hot regenerators enter the annular heating chamber A at one side of the furnace, as shown by the arrows in Fig. 10, and pass all round it, the products of combustion escaping at the opposite side into the cold regenerators. The direction of the current is reversed at intervals exactly as in the plate glass furnace already described, by means of the reversing valves H and J in the air and gas passages, Figs. 11 and 12. Furnaces of this construction have lately been got to work at Namur in Belgium and at Montluçon in France, and several others of the same description are in course of erection at the present time. The furnace just started by Messrs. Osler in Birmingham also partakes of this form, being made semicircular.

In setting out each individual furnace, the heating effect required, the quality of the fuel employed, and the particular nature of the process to be performed, have to be considered. The amount of heat required determines the capacity of the regenerators; and the gas regenerators require fully as large a capacity as the air regenerators, and sometimes even a greater. This would perhaps hardly be expected, but will be seen to be the case from the following considerations. The gases proceeding from the gas producers are a mixture of olefiant gas, marsh gas, vapour of tar, water and ammoniacal compounds, hydrogen gas and carbonic oxide; besides nitrogen, carbonic acid, some sulphuretted hydrogen, and some bisulphuret of carbon. The specific gravity of this mixture averages 0.78, that of air being 1.00; and a ton of fuel, not including the earthy remnants, produces according to calculation nearly 64000 cubic feet of gas. By heating these gases to 3000° Fahr. their volume would be fully six times increased, but in reality a much larger

increase of volume ensues, in consequence of some important chemical changes effected at the same time. The olefiant gas and tar vapour are well known to deposit carbon on being heated to redness, which is immediately taken up by the carbonic acid and vapour of water, the former being converted into carbonic oxide and the latter into carbonic oxide and pure hydrogen. The ammoniacal vapours and sulphuretted hydrogen are also decomposed, and permanently elastic gases with a preponderance of hydrogen are formed. The specific gravity of the mixture is reduced in consequence of these transformations to 0.70, showing an increase of volume from 64000 to nearly 72000 cubic feet per ton of fuel, taken at the same temperature. This chemical change represents a large absorption of heat from the regenerator, but the heat is given out again by combustion in the furnace, enhancing the heating power of the fuel beyond the increase due to elevation of temperature alone.

The chemical transformation is also of importance in preventing "sulphuring;" for it is believed that the sulphur in separating from its hydrogen takes up oxygen supplied by the carbonic acid and water, forming sulphurous acid, a firm compound, which is not decomposed on meeting with metallic oxides in the furnace. This view is so far borne out by experience that glass containing a moderate proportion of lead in its composition may be melted in open crucibles without injury, instead of requiring covered pots for the purpose as in ordinary furnaces. In dealing with the highest quality of flint glass however it is found necessary to retain covered pots; but every other description of glass is melted in open pots. In all branches of glass manufacture, saving of fuel is of relatively small moment as compared with the improvement effected in the colour and general quality of the glass by the use of the regenerative gas furnace, owing to the absence of dust and cinders and the higher degree of temperature which may with safety be maintained throughout the heating chamber.

These advantages of the regenerative gas furnace are of equal value in the case of puddling and welding iron. Plates 10 and 11 represent a Puddling Furnace constructed on this plan. Fig. 13 is a longitudinal section of the furnace, Fig. 14 a sectional plan of the

puddling chamber, and Fig. 15 a sectional plan of the regenerators; Fig. 16 is a transverse section at the end of the furnace, and Figs. 17 and 18 are vertical sections through the gas and air passages.

The four regenerators C are in this case arranged longitudinally underneath the puddling chamber A, which may be of the usual form. In order to complete the combustion of the gas and air in passing through the comparatively short length of the puddling chamber, it is necessary to mix them more intimately than is requisite in the large glass furnaces previously described. For this purpose a mixing chamber O, Fig. 13, is provided at each end of the puddling chamber, and the gas and air from the regenerators are made to enter the mixing chamber from opposite sides, as shown in Fig. 16; the gas aperture E is moreover placed several inches lower than the air aperture F, so that the lighter stream of gas rises through the stream of air while both are urged forward into the puddling chamber, and an intense and perfect combustion is produced. The mixing chambers O are sloped towards the furnace, as shown in Fig. 13, in order to drain them of any cinders which may get over the bridge. The reversal of the current through the furnace is effected about every hour by the reversing valves H and J in the air and gas flues, the arrangement of which is exactly similar to that already described in the glass furnace: the supply of gas and air is regulated by the throttle valves L, and the draught through the furnace by the ordinary chimney damper.

This same arrangement, with obvious modifications, may be applied also to blooming and heating furnaces, the advantages in both cases being a decided saving of iron, besides an important saving in the quantity and quality of the fuel employed. The space saved near the hammer and rolls by doing away with fireplaces, separate chimney stacks, and stores of fuel, is also a considerable advantage in favour of the regenerative gas furnace in ironworks. The facility which it affords for either concentrating the heating effect or diffusing it equally over a long chamber, by effecting a more or less rapid mixture of the air and gas, renders the furnace particularly applicable for heating large and irregular forgings or long strips or tubes which have to be

brought to a welding heat throughout. It has already been applied to a considerable extent in Germany for heating iron, having been worked out there under the direction of the writer's eldest brother, Dr. Werner Siemens, who has also contributed essentially to the development of the system. The furnaces at the extensive iron and engine works of M. Borsig of Berlin are being remodelled for the adoption of this system of heating, as have also been those at the imperial factories at Warsaw.

Another important application of the regenerative gas furnace is as a Steel Melting Furnace, in which the highest degree of heat known in the arts is required, presenting consequently the greatest margin for saving of fuel. Plate 12 represents a regenerative steel furnace which has been in satisfactory operation in Germany for a considerable length of time, being worked with lignite, a fuel little superior to peat in heating power. This application of the regenerative gas furnace is indeed rapidly extending in Germany, but has not yet practically succeeded in Sheffield where it was also tried: it is however in course of application at the Brades Steel Works near Birmingham. Fig. 19 is a longitudinal section of the furnace, Fig. 20 a transverse section, and Fig. 21 a sectional plan.

The two pairs of regenerators C C, Figs. 19 and 21, are situated at the ends of the long melting chamber A, in which the steel melting pots B B are arranged in a double row. The chamber is covered with iron cramped arch-pieces P, any of which can be readily removed for getting at the pots. The arrangement of the reversing valves and the air and gas flues is similar to that in the glass furnace previously described.

Other applications of the regenerative gas furnace are being carried out at the present time: among which may be mentioned one to brick and pottery kilns for Mr. Humphrey Chamberlain near Southampton, for Messrs. Cliff of Wortley near Leeds, and for Mr. Cliff of the Imperial Potteries, Lambeth; also to the heating of gas retorts at the Paris General Gas Works, and at the Chartered Gas Co.'s Works, London. The description already given however is sufficient to show

the facility with which this mode of heating may be adapted to the various circumstances under which furnaces are employed. The important application of the regenerative system to hot-blast stoves for blast furnaces by Mr. E. A. Cowper has already been separately communicated to this Institution (see Proceedings Inst. M. E., 1860, page 54).

The experience hitherto obtained with the regenerative mode of heating shows that it is attended with the greatest proportionate advantage in localities where good coal is scarce but where an inferior fuel abounds. This applies most forcibly to the South Staffordshire district, where the best coal in lumps is worth 12s. 6d. per ton, whereas good slack can be had at 3s. or 4s. per ton. The question gains moreover in importance when it is considered that, according to the best authorities, the Thick coal of the district is coming to an end, while millions of tons of coal dust have accumulated, of no present commercial value, which on being converted into gas in the manner described by means of the gas producers would acquire a heating value equal at any rate to the same weight of the best coal in the manner in which it is at present used. Considering also the proximity of the pits to the ironworks in this district, it may be suggested whether the gas producers being of very simple construction might not with advantage be placed near the banks of fuel above or even under ground, the gas being conveyed to the works by a culvert so as to supersede carting of the fuel. Such an arrangement might notably contribute to perpetuate the high position which South Staffordshire has so long maintained as an iron producing district.

Mr. SIEMENS observed that the essential features of the regenerative gas furnace described in the paper, as now matured and carried out in practice, were the separate gas producers, in which the solid fuel was converted into a gaseous form for use in the furnace, and the regenerators, in which the gas and air were each raised to a high

degree of temperature previous to their mixture and combustion in the furnace, whereby the heat produced by the combustion was very greatly increased. In the gas producers the fuel underwent a slow digestion, and the whole of the combustible constituents were drawn off into the furnace in the form of gas, while the incombustible ash or valueless portion of the fuel was left behind. The gas produced was of a crude nature in its original state, and much inferior to common gas for illuminating or heating purposes, and if burnt only with ordinary air would give very poor results: but it underwent a further change in the regenerator where it was heated up to about 3000° Fahr., at which temperature the several gaseous compounds contained in it became decomposed, the rich carburetted hydrogen depositing carbon which was at once taken up by the vapour of water present, producing carbonic oxide and hydrogen; so that there was then present the greatest amount of free hydrogen, which had three or four times the heating power of any other gas. The air used for burning the gas was also heated by the regenerator up to about 3000° and then mixed with the gas at the same temperature, producing perfect and most intense combustion: the regenerative system thus presented the means of attaining an almost unlimited degree of temperature. At the same time there was no great current or draught through the furnace, since the chimney draught was not required in this furnace to urge the combustion as in ordinary furnaces heated by solid fuel, and the cutting draughts destructive of ordinary furnaces were therefore entirely avoided.

Mr. J. T. CHANCE said the regenerative gas furnace had been tried at Messrs. Chance's glass works, and it certainly bid fair to produce a considerable change in the mode of maintaining the high temperature required in glass works. He was not in a position at present to state definitely that success was thoroughly obtained in every particular, simply because it required time to develop all the difficulties or peculiarities that might arise in the application of the furnace to a new process of manufacture, which might not be anticipated prior to actual trial. No difficulties however had occurred yet in the working of their large melting furnace, containing eight large pots holding two tons of glass each, which had now been

in regular work for three weeks with complete success; and there appeared no reason to anticipate any difficulty arising. On the contrary he expected the greatest advantages in glass furnaces from the plan of converting the fuel into gas before letting it enter the furnace, of the superiority of which there could be no doubt; for it was evident it must be far better to have gas alone burnt in the furnace, producing a perfectly clean flame, free from all impurities, than to have the gas generated from solid fuel in the furnace itself, when the work was necessarily exposed to all the impurities arising from the fuel, especially at the time of stirring up the fire. The economy of the furnace at their works had not yet been definitely ascertained, as it had not been long enough at work at present for that purpose, but he expected there would certainly be economy as compared with ordinary furnaces.

They had had a smaller furnace on the same principle at work previously for a year, for the purpose of making a preliminary trial of the plan before attempting to carry it out on so large a scale as the new furnace that had now been erected. In this first furnace some deposit had occurred in the regenerators, which he hoped would be obviated in the larger furnace. In making glass a great volatilisation took place of the foreign substances contained in the melted materials, which in the ordinary furnaces passed off through the working holes; but in the new regenerative furnace the volatilised gases would all have to pass through the regenerators, and he was desirous of seeing whether this would cause any trouble by choking the passages of the regenerators after working for a length of time: but even if any such effect were produced, it would be merely a question of expense of renewing the regenerators when required. The principle of the furnace was certainly a very perfect one, and on first becoming acquainted with it he was particularly struck with the scientific principle on which the regenerators acted, separating the heat passing off from the furnace, and retaining it all in the furnace, letting the products of combustion pass off into the chimney at a low temperature; and the quantity of heat thus gradually accumulating in the regenerator was then all given back again to the furnace when the draught was reversed. In the practical application of the regenerative furnace for glass making he had been surprised

that so few difficulties were met with, the new large furnace having gone on in regular work with entire success from the first start: the furnace thus appeared not only perfect in theory, but also to present no insuperable difficulties in practice.

The CHAIRMAN asked what was the experience at Messrs. Lloyd and Summerfield's glass works as to working and economy of fuel with the new furnace.

Dr. LLOYD replied that they had had one of the regenerative ten pot furnaces in operation nearly twelve months for flint glass making, and every month's experience of its working convinced him that the high opinion he originally formed of its value was fully deserved, notwithstanding some difficulties that had been met with. The regenerative system appeared to him one of the most beautiful adaptations of science to practical art, and he was so much struck with the soundness of the principle that he went at once to see a small glass furnace that was working on that plan in Yorkshire; and being satisfied of the theoretical perfection of the plan, he adopted the new furnace immediately at his own works for flint glass making. In this case the melting pots were all closed in at the top, and he had therefore no apprehension of the regenerators getting clogged after working a length of time, since all the vapours in melting escaped at the mouths of the pots and did not pass into the regenerators at all. Some inconvenience had arisen occasionally at first by pots breaking near the bottom, in consequence of the siege being too thin; but this was effectually remedied by raising the siege with fireclay by degrees in setting new pots. He had adopted the new furnace mainly with a view to saving in fuel, and particular attention had been paid to ascertain the real economy in this respect. It was built of about the same capacity as an old ten pot furnace, which they had had in use for several years previously, heated with large best coal; the large coal was found more economical in the end than coal of an inferior and cheaper description, but the consumption was very considerable. The result of the comparison between the two furnaces was that the old furnace consumed as nearly as possible double the quantity of fuel required in the regenerative furnace, the average of the year being about 35 tons per week in the old and only 16 to 17 tons

per week in the new : but the coal now used in the new furnace cost only one third as much per ton, being entirely small coal at 4s. per ton instead of large coal at 12s. ; so that the actual cost of fuel in the new furnace was reduced to one sixth of that in the old, doing the same amount of work.

This was a very important economy in manufacture, but there were also other prospective advantages in the new furnace to be taken into account, in respect of durability and maintenance. In the old furnaces the cost and inconvenience of rebuilding were a serious consideration ; but the durability of the new furnace seemed likely to be much increased by the heat being kept so equable, with an entire freedom from cutting draughts : the experience of the twelve months' working of their new furnace was that the wear and tear were so trifling, although a very high temperature was maintained, that he expected it would last three or four times as long as the old furnace, judging from the state of the edges of the bricks in the new furnace, which were still nearly as sharp as when it was built. This increased durability might indeed be reasonably anticipated, because no alkaline and earthy matters from the fuel were now carried into the furnace but they were all left behind in the gas producer, and nothing went into the furnace but gases that were wholly combustible and almost entirely free from impurities. The flame produced was so pure that they were now able to carry on the working as it is termed of the glass in the same furnace as the melting, instead of in a separate heating furnace where the glass articles being worked were protected from the fuel : this was utterly impossible in the old furnaces heated direct by coal, because pure glass was completely spoiled in a few minutes if exposed to the flame of ordinary furnaces, and flint glass could not be melted in them except in covered pots to protect it from contact with the flame ; but in the new furnace not more than 5 per cent. of the articles had been injured, and that was observed to occur only occasionally when there had been some irregularity in the working of the gas producers on account of their not having been correctly managed. The very uniform and intense heat obtained in the new furnace enabled the melting to be done quicker than before, improving both the quantity and quality of the make : a considerable saving might also be effected in the

proportion of fluxes required in the glass, a smaller quantity being necessary with the greater heat obtained. He considered that for all manufactures where a high temperature was required to be constantly maintained without risk of variations the regenerative gas furnace possessed great advantages and was deserving of careful attention.

Mr. W. HADEN enquired whether in applying the new furnace for puddling there was any practical difficulty in varying the intensity of the flame in the puddling chamber to suit the state of the iron.

Mr. SIEMENS replied that there was no difficulty in keeping up an abundant supply of gas if there were enough gas producers and if the passages to the furnace were large enough; the puddling chamber could then be completely filled with flame at any moment, or the flame could be as instantly stopped, by means of the regulating valves and chimney damper. By having separate air and gas valves the chemical nature or heating power of the flame could also be regulated to any desired degree, by altering the proportion of air admitted with the gas, so as to produce any required effect from a smoky flame to a pure bright flame. In the furnace for flattening the cylinders of sheet glass a quantity of bright clean flame was required for softening the glass without melting it; but in the melting furnace on the contrary an intense soaking heat was wanted with very little variation: and both sorts of heat were obtained in the new furnace from the same gas main, by simply regulating the quantities of air and gas admitted. Of the puddling furnaces two were now just being started in the South Staffordshire district, but about twenty puddling and heating furnaces had been at work in Germany for some months already with complete success.

The CHAIRMAN asked how long it took to work off a heat in puddling in the regenerative furnace.

Mr. SIEMENS said they had not yet obtained any absolute results with the regenerative puddling furnaces in this country, but at present the time of working a heat was about the same as in the ordinary puddling furnaces. The puddling furnaces working on this plan near Wolverhampton were not yet in a complete state for operation as they had been expected to be before this time, on account of a defect in the chimney flue and in the drainage of the premises. No permanent

difficulty could be anticipated in carrying out the new puddling furnace in practice, on account of the large amount of experience gained in the application of the regenerative furnace for other purposes.

Mr. T. W. PLUM asked whether the draught was obtained by a separate chimney to each furnace as in ordinary puddling furnaces.

Mr. SIEMENS replied that there was only one chimney to a number of furnaces, and the draught was simply regulated by a separate damper to each furnace. The chimney was not required to be lined with firebrick, but was built of red bricks, as the heat passing off from the puddling chamber was all arrested in the regenerators and the chimney was always cool. The chimney damper regulated only the force of draught in each furnace, but the quantity and quality of flame were regulated by the gas valve.

Mr. W. MATHEWS enquired whether there was any tendency in the regenerators to fur up with deposit from the inferior description of fuel used for the furnace.

Mr. SIEMENS replied that no such result had taken place in the regenerators, because the steam mixed with the gas would volatilise any carbon that might otherwise be deposited on the walls of the regenerator: it was for this purpose that care was taken to supply an excess of vapour of water from the water trough in the grate of the gas producer.

Mr. W. MATHEWS asked whether the materials of the furnace were not liable to vitrify under the great heat to which they were exposed, and whether any limit had been found to their endurance.

Mr. SIEMENS replied that a regenerative heating furnace had been three years in constant work at Messrs. Marriott and Atkinson's steel works, Sheffield, heating the steel for the rolling mill, and no inconvenience had been experienced from this cause. Mr. Atkinson was prevented from being present at the meeting himself as he had wished, but had sent a letter expressing his satisfaction with the furnace, as especially advantageous for heating steel on account of the uniformity of the heat obtained in it. The glass melting furnace at Messrs. Lloyd and Summerfield's had also been in constant work for nearly a year without sustaining any injury from the great heat employed in it.

Mr. W. MATHEWS asked whether the temperature was really as high as had been supposed in the glass furnace; and what means were used for correctly measuring the degree of heat.

Mr. SIEMENS said the temperature in the furnace was at least a full welding heat of iron, as a bar of iron held in it dropped melted in half a minute; the hot end of the regenerator had a temperature of about 3000° Fahr., and the heat in the furnace must of course be greater. For measuring such high temperatures he made use of the pyrometer described at a previous meeting (Proceedings Inst. M. E., 1860, page 59), consisting of a well protected vessel containing a measured quantity of water, and a piece of copper or platinum of definite size, which was exposed for a sufficient length of time to the heat to be measured and was then dropped into the water; the rise of temperature produced in the water showed the degree of heat upon a thermometer scale graduated in the proper proportion, and the results thus obtained must certainly be correct within 10° or 15° Fahr.

The CHAIRMAN enquired what were the results of working of the regenerative furnace at Messrs. Russell's tube works at Wednesbury.

Mr. B. L. BROWN said they had had one regenerative furnace at work for three months at their works as a heating furnace for bending the wrought iron strips for the tubes, and it had given complete satisfaction: the temperature was kept up constantly with great regularity, and there was no fear of the iron being unequally heated in different parts of the furnace or being injured by any impurities in the fuel. Another furnace on the same principle for welding the tubes had now been added at their works, but it had been in full operation for only about three weeks, and a definite statement of the results could not therefore be given; but up to the present time it had also proved thoroughly successful.

Mr. S. H. BLACKWELL had seen the regenerative furnaces at Messrs. Chance's and Messrs. Lloyd and Summerfield's glass works, and was exceedingly pleased with their operation. It would be premature to say much about puddling with the new furnace till it had been longer at work and afforded definite results; but he certainly thought there were some points about it which would be of the greatest benefit in puddling, particularly the saving of fuel by recovering all

the waste heat passing off from the puddling chamber, and the very efficient heat obtained for working the iron. Also the peculiar balancing of pressure for ensuring always a slight excess of pressure inside the furnace was an improvement of great value, preventing the cutting draughts that took place in ordinary furnaces through the puddling door and other openings, which caused a serious waste of the iron by oxidation. He had not yet had an opportunity of seeing the new puddling furnace at work, but had heard that one had been at work already about a month in the neighbourhood.

Mr. SIEMENS said that was the case, but the works happened to be just now stopped by the water being out of the canal; he understood however they were already starting to work again immediately.

Mr. S. H. BLACKWELL asked whether any results had been obtained as to the yield of iron in puddling with the new furnace.

Mr. SIEMENS replied that rather larger yields were obtained with the regenerative puddling furnace, but it had not been long enough at work yet to give any definite results. The puddling furnaces at work in Germany however showed at least 4 or 5 per cent. increase in the yield of iron, and this result was indeed to be expected, because the new furnace was free from the cutting action of the flame produced by a strong draught, and the ball was surrounded on all sides by an equally hot flame.

Mr. G. THOMSON enquired what was the cost of applying the regenerative system to present puddling furnaces.

Mr. SIEMENS replied that the alteration of present furnaces would be attended with a considerable expense, as there was all the extra bottom brickwork of the regenerators, besides the separate gas producers and the valves and mains; but the separate chimneys for each furnace were saved, and the cost of maintenance was greatly reduced, judging from the condition of the glass furnaces that had been twelve months at work. In new works however the cost of construction of the regenerative puddling furnaces would not much exceed the total cost of the present furnaces complete; and the new furnaces had the advantage of occupying only their own space, without requiring room for a coal pen to each furnace; they could thus be built closer together and consequently more could be brought within reach of one hammer.

The CHAIRMAN enquired whether the pig iron was heated before being put into the puddling furnace.

Mr. SIEMENS said it was not heated, but put in cold.

The CHAIRMAN enquired what was the cost of the new puddling furnace, taking that of an ordinary furnace at about £150.

Mr. SIEMENS thought a pair of the new puddling furnaces would cost about £300 complete. The regenerative glass furnaces hitherto erected had been very expensive in construction, having heavy iron plates in the sieges and a great deal of ironwork in the fittings of the furnace and in the gas producers, much of which had been greatly reduced or dispensed with in the furnaces subsequently put up. In starting the new plan of furnace he had thought it best to keep all the work very substantial, to be on the safe side for strength and durability; and the gas producers had also been provided each with a separate gas tube and valve, so that each could be shut off from the furnace if desired, to avoid risk of the furnace being interfered with in its working by a defect at any particular point.

Mr. J. T. CHANCE observed that one other circumstance that ought to be mentioned about the regenerative furnace was the complete absence of smoke, which was a considerable advantage in its favour: excepting at distant intervals when the tar was being burnt out from the gas mains, there was really no smoke at all from the chimney, the combustion of the gases in the furnace being perfect. In large towns freedom from smoke was so great an advantage that this of itself would be a sufficient reason for adopting the regenerative furnace, even if in other respects it were only as good as ordinary furnaces, instead of being as he had found it so much superior to them.

Mr. E. A. COWPER thought the application of the new furnace in ironworks as a mill furnace would be attended with great advantages and would not involve any serious difficulty. It would be particularly advantageous for large work, such as heavy shafts of very large diameter, as it would afford the means of getting a soaking heat through to the centre of the mass, without any fear of injuring the iron by burning, since there was no free oxygen present in the furnace, as the whole of it was completely burnt at the moment of entering the furnace.

The CHAIRMAN observed that the subject of the paper was one of great interest and importance, and moved a vote of thanks to Mr. Siemens for his paper, which was passed.

After the Meeting a number of the Members dined together in celebration of the Fifteenth Anniversary of the Institution.

PROCEEDINGS.

24 APRIL, 1862.

The GENERAL MEETING of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 24th April, 1862; ALEXANDER B. COCHRANE, Esq., Vice-President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected :—

MEMBERS.

THOMAS BOUCH,	Edinburgh.
WILLIAM CARPMAEL,	London.
JAMES CLARK,	Leeds.
SAMUEL H. F. COX,	Birmingham.
SAMUEL HINGLEY,	Dudley.
J. C. FRANK LEE,	London.
WILSON LLOYD,	Wednesbury.
RICHARD CHRISTOPHER MANSELL, .	Ashford.
FREDERICK THORPE MAPPIN, .	Sheffield.
EDWARD REYNOLDS,	London.
WILLIAM SIMPSON,	London.
JOHN TAYLOR, JUN.,	London.
CHARLES TROWARD,	Doncaster.
ALFRED UPWARD,	London.
JOSIAH VAVASSEUR,	London.
FRANCIS WILLIAM WEBB,	Crewe.
HENRY ARTHUR WEBB,	Stourbridge.
CHARLES WELLS,	Bilston.

The following paper was then read :—

ON THE CONSTRUCTION OF LIGHTING APPARATUS FOR LIGHTHOUSES.

BY MR. ARMAND MASSELIN, OF BIRMINGHAM.

The subject of Dioptric Lighthouse Apparatus is intimately connected with that of a paper read at a former meeting of the Institution, namely, iron lighthouse towers (see Proceedings Inst. M. E., 1861, page 15); and the construction of the optical part of this apparatus is of considerable mechanical interest.

The construction and illumination of lighthouses constitute one of the most important of public undertakings at the present day. The development however of the comparative perfection now attained in these two departments has been gradual and unequal. During the century that has elapsed since the erection by Smeaton of the Eddystone lighthouse, when engineering was greatly in advance of practical optics, the art of building towers has received few improvements, while the apparatus for illuminating them has by the introduction of the dioptric system acquired a striking degree of excellence. During nearly the whole of the last century and in some places as late as 1816, open coal fires, improved occasionally by a flat brass plate placed on the land side, were the rude means usually resorted to for producing light. The Eddystone tower had a lantern to protect the weak light given out by the few miserable tallow candles which were then used, and only in 1807 were these replaced by lights furnished with silver-plated parabolic reflectors. Distinction of one light from another by its appearance at night, a point nearly as important as the range of the light, was of course out of the question.

Lights on the catoptric or reflecting system, composed of silver-plated parabolic reflectors provided with plain cylindrical burners

placed in the focus of each, were used exclusively until 1822, when Augustin Fresnel invented and erected on the Cordovan tower his first dioptric or refracting light. The catoptric or reflecting system was, in comparison with the imperfect means previously available, a valuable improvement, and under later modifications is still in extensive use in this country; but having many serious imperfections it is gradually disappearing before the dioptric or refracting system.

The latest optical and mechanical improvements in the dioptric system are illustrated by the fixed light of the Smalls Rock near Milford Haven, and the revolving light of Lundy Island, both constructed by Messrs. Chance, and the latter attested by mariners as the most powerful light in Great Britain, flashing over 35 miles of the Atlantic. In the present paper it is intended only to notice briefly the existing state of reflecting and refracting apparatus and the relative merits of each, before giving the particulars of their mechanical construction.

In the Dioptric or refracting system, only one lamp is used, placed in the vertical axis of the apparatus. In fixed lights, as shown in Fig. 1, Plate 13, the middle or dioptric part having the lamp in its centre is cylindrical, and composed of a series of refracting rings or lenses A A, shown black, which are so shaped as to give a horizontal direction to all the rays of light that fall from the lamp upon their inner faces. All the rays of light passing above and below these middle lenses are received by the upper and lower catadioptric prisms B B, shown black, by which they are also transmitted horizontally after refraction and total reflection in the prisms. Every piece of glass in the apparatus forms a portion of a horizontal ring or belt, having its centre in the vertical axis of the apparatus, as shown in the plan, Fig. 3, Plate 15. The rays of light given out by the lamp are thus collected and transmitted equally over the horizon, and the light is rendered luminous throughout its entire height. The glass prisms are fixed in eight gun-metal standards, forming an octagonal frame, each prism being supported in the centre by passing through an intermediate standard, as shown in the plan, Fig. 3.

In revolving lights, as shown in Fig. 2, Plate 14, the transverse section of the refracting lenses A and prisms B is precisely the same as in fixed lights: but in revolving lights the rings of glass are concentric round a horizontal axis passing through the brightest part of the flame, as shown by the dotted lines in Fig. 2, instead of round the vertical axis. The circumference is divided into eight flat faces, as shown in the plan, Fig. 4, Plate 15, each composed of a series of prismatic rings and segments having one common focus; the light emanating from the lamp is thus transmitted by each face in a brilliant flash extending over the whole width and height of the face; and the whole apparatus being made to revolve by clockwork, every point of the horizon is illuminated by a succession of brilliant flashes corresponding to the several faces, and at intervals of time determined by the speed of revolution. By the use of fixed and revolving lights or combinations of them in various ways, lights of distinct appearance are produced in a number sufficient for all purposes that are required in practice.

Dioptric lights are made of six different sizes or "orders" as they are termed; and the following table gives the internal radius of the apparatus or the focal distance in each order, the number of wicks in the lamp, and the consumption of oil in lbs. per hour, and in gallons per year, assuming the light to burn 11 hours per night on an average throughout the year.

Orders of Dioptric Lights.

Order.	Internal radius of Light.	Number of Wicks.	Consumption of Oil.	
			Lbs. per hour.	Gallons per year.
	Inches.		Lbs.	Gallons.
First	36·22	4	1·65	736
Second	27·55	3	1·10	490
Third	19·68	2	0·41	130
Fourth	9·84	2	0·26	116
Fifth	7·28	1	0·17	76
Sixth	5·90	1	0·17	76

The three largest orders are generally termed sea lights, and the three smaller ones harbour lights. The first order as the most important will alone be referred to in this paper, the others differing merely in size and number of prisms and lenses.

In the Catoptric or reflecting system a number of parabolic reflectors are used, ranged round a framework according to the purpose required, with a lamp in the focus of each reflector. In a fixed light these reflectors, frequently as many as 24 or 30 in number, are arranged round the frame so as to equalise the light as much as possible in all directions. In revolving lights the reflectors are mounted on a revolving frame, having generally three faces, each of which carries an equal number of reflectors. Three flashes of light are thus produced, which illuminate successively every point of the horizon at intervals regulated by the speed of revolution. The loss of light in this system is necessarily very large: indeed nearly the whole of the light from the front of the flame is directly lost by natural divergence, the reflectors transmitting to the horizon only the rays emanating from the back of the flame, and of this light nearly 50 per cent. is lost by the absorption that always takes place in reflection by metallic surfaces.

Comparing the two systems together, it is evident that for fixed lights no possible combination of reflectors can distribute a zone of light of equal intensity round the horizon, whilst this effect is completely obtained by the dioptric system. It is found that whilst only $3\frac{1}{2}$ per cent. of a plain open light would be available round the entire horizon, 17 per cent. is obtained by the use of the best reflectors, but 83 per cent. is obtained by the use of the dioptric lights. The extreme divergence of the rays of light from a usual 21 inch reflector with a 1 inch flame is about 14 degrees; but the variation of the intensity of the flash emitted over this angle is very large indeed, the intensity of the light being only 16 per cent. on the sides of what it is in the axis of the flash, showing how great is the irregularity of the light spread over the horizon. Also the numerous fastenings of the reflectors and lamps frequently get loosened, increasing greatly the irregularity of

the light. Nor is the whole amount of divergence taken vertically useful; for, as will be shown afterwards, the lower portion of the vertical divergence required to illuminate the sea between the horizon and the land is but a very small amount. In uniformity of light therefore throughout the horizon illuminated the dioptric system is very greatly superior to the reflecting for fixed lights. With regard to economy of oil, fifteen reflector lamps together consume as much oil as the one central lamp in the dioptric light, and the saving therefore amounts to 50 per cent. in favour of the latter compared with a reflecting light of the largest practicable size, having thirty lamps, but greatly inferior in illuminating power to the dioptric light.

Another very important consideration is the durability of the apparatus. The longest time that reflectors will last, even when treated with the greatest care, is from 25 to 30 years; their thin silver coating will have completely disappeared at the end of that time. With moderate care and no necessity for readjustment dioptric lights may be considered as imperishable; the lenses and prisms never lose their correct form and first polish, never require renewal, and are kept always equally efficient with a far less amount of daily labour than that required for reflectors. The number of attendants or keepers required is the same in both cases, and the first outlay may be considered as generally equal.

For revolving lights however the catoptric system presents fewer points of inferiority as compared with the dioptric; for by sufficiently increasing the number of lamps and reflectors on each face of the revolving frame, a light of equal intensity to the dioptric might be produced. The illuminating power, consumption of oil, durability, and original outlay will therefore be the chief considerations to determine the relative advantages of the two systems for revolving lights. The effect of only one of the eight faces composed of annular lenses in a first order dioptric light is equal to that of eight of the largest reflectors in use, 21 inches in diameter; and consequently to produce by reflectors the effect of the best dioptric light a lantern would have to be provided capable of accommodating from 56 to 72 reflectors, an arrangement all but impracticable. Moreover at the time when most of the experiments were made both in this country

and abroad for comparing the intensity of revolving dioptric and reflecting lights, the dioptric lights were composed merely of the central or singly refracting part AA, Fig. 2, Plate 14. But in the present holophotal system, in which the upper and lower reflecting prisms BB are made to continue and extend the action of the central refracting lenses AA as already described, the intensity of the dioptric lights has been nearly doubled and the comparison rendered so much more unfavourable to the reflecting system.

The only objection which has been seriously urged against the dioptric system is the use of only a single central lamp, on account of any difficulty in its management affecting the whole light, or danger of its sudden extinction. This is met however by the successful experience of forty years with an immense number of lights in different parts of the world. Hardly ever has such a case occurred; and as spare burners are invariably supplied and required to be always kept ready for use, a few minutes only would suffice to remove the defective burner and replace it by another.

The Lamp necessarily forms a very important part of the lighthouse apparatus, in the efficiency of which it is an essential element. The lamps generally used in the larger dioptric lights are of the class known as mechanical lamps, in which the oil is forced from a reservoir into the burner by means of a pump worked by clockwork driven by a weight. Although this construction of lamp is simple enough, it requires that the keepers should be trained to its use and should have a thorough knowledge of the way of taking it to pieces for cleaning and then putting it together again, before they are sent to their respective lighthouses. As this precaution was not at first universally adopted in lighthouses, complaints were made against the mechanical lamp; and in consequence lamps of the simplest possible construction but inefficient in action came into use in this country, consisting simply of a side reservoir communicating by a tube with the burner, the level of oil in both being the same. The consequent absence of overflow prevented a high flame from being obtained and greatly impaired the efficiency of the light, which doubtless considerably retarded the adoption of the dioptric system. Pressure lamps were also made more

lately, consisting of a large cylindrical oil reservoir containing a piston fitted with a cupped-leather packing, the pressure being obtained by a number of small weights arranged round the piston, whereby the oil was forced through a side tube into the burner. These lamps however presented many inconveniences: the pressure could not conveniently be varied, since the addition of one weight tended to cant the piston out of its horizontal position and allow the oil to escape at the opposite side. The cylinder being made only of sheet brass and therefore not perfectly cylindrical, a considerable difference of diameter between the piston and cylinder was required; and when the oil became rather warm, the leather got so soft that it was liable to turn over and render the lamp useless. The piston being entirely submerged lost a portion of its weight; and whenever the pressure had to be varied, the weights taken out were covered with oil, and there was a great waste by the oil being spilled: there was also a liability to leakage from the body of the lamp being made of several parts soldered together.

The conditions the lamps are required to fulfil are:—a constant and even supply of oil to the burner, equal to fully four times the consumption; simplicity of construction, so that any unskilled mechanic can take the lamp to pieces and put it together again; freedom from liability to derangement; and an accurate fit of the various parts, so that all duplicate parts will fit equally well.

To meet these requirements the writer designed the construction of lamp shown in Fig. 5, Plate 16, which has fully answered the purpose. The brass cylinder C, containing the oil for the lamp, is cast solid in one piece with the bottom, and bored out truly cylindrical, and is fitted with a turned piston D having a cupped-leather packing; the three piston rods are connected at top to a wrought iron ring E, Fig. 6, to which are attached the side rods passing down outside the cylinder to the wrought iron ring below, which carries the weight F. The piston is steadied against any small lateral oscillation by six leather guides G fixed round its circumference; and any air underneath is let out through the centre vent cock H. The oil is forced out at the bottom of the cylinder through the upright tube I leading to the burner J, the quantity

being accurately adjusted by a conical regulating valve K, having an index on the screwed handle which shows the quantity of oil supplied to the burner per minute or per hour. When the piston has descended to the bottom of the cylinder, it is wound up again by the rack and pinion L, Fig. 7, underneath the cylinder; and the oil is prevented from being drawn down from the burner by a check valve consisting of a small ball M situated in the feed pipe I. The burner remains therefore constantly fully supplied with oil; and the time occupied by winding up the weight being only a few seconds, the overflow of oil is not even visibly affected. As impurities from the charring of the wicks, and especially a quantity of flue or dust from the cotton wicks, are constantly brought into the cylinder by the overflow oil and afterwards drawn under the piston, these would find their way up through the feed tube I into the burner J, which would cause a stoppage of the supply of oil to the wicks. To prevent this, a fine wire sieve N is placed in a box in the feed tube I, which arrests any impurities in the oil and can be opened and cleaned out occasionally in the day time when required. Should the sieve get stopped up during the night while the lamp is burning, it can be changed in less than a minute, which does not interfere with the working of the lamp. Each wick is provided with two oil tubes, whereby a constant supply of oil to each wick is obtained, instead of all the wicks being fed by a single exterior tube, as in the previous lamps.

In order to produce a proper illumination of the horizon by this light, it is essential that the full height of flame should be kept up, maintaining the flame correctly in the focus of the apparatus, without which the best optical apparatus would be imperfect in action. For this purpose the overflow of oil must never be less than three or four times the actual consumption; otherwise the wicks will burn down to the edge of the burner, and the intense heat produced would very soon destroy the burner itself. Moreover when the supply of oil is too small, the heat of the flame has time to act on the small overflow, and considerably deteriorates the quality of the oil; and the overflow being all returned into the reservoir, the quantity of deteriorated oil in the reservoir increases until it is impossible to maintain a good flame.

K

The proper shape, diameter, and position of the shoulder or contraction O, Fig. 5, in the glass chimney used for the lamp is of special importance, since this has a direct influence upon the shape and height of the flame and consequently upon the intensity of the light produced. Too sudden a contraction of the glass causes the flame to be reduced in height, especially that of the outer wick; and no efficient flame can be obtained unless all the wicks give a flame of equal height. Too large or too high a shoulder of the glass prevents a rapid combustion, and consequently prevents a bright flame from being obtained, and a long flickering one is the result. An adjustable damper is placed over the glass; and above this a continuous pipe of about 6 feet in length from the burner is required to produce a sufficiently rapid draught to support the combustion. When the lamp is lighted at first, the wicks are kept low for some time and gradually made to rise for about twenty minutes, until they rise about $\frac{1}{4}$ inch to $\frac{3}{8}$ inch above the burner; then by a slight adjustment of the wicks to obtain equal height of flame, and the occasional shutting or opening of the damper P, Figs. 1 and 2, a most intensely bright and high flame is obtained and kept up during the whole of the night. The diameter of the burner and flame of a first order lamp is $3\frac{1}{2}$ inches, and with proper management the flame is kept up constantly to a nearly uniform height of 4 inches.

The oil used in lamps for lighthouses is the refined colza oil or rape-seed oil, which is the only oil fit for the purpose and is much superior to the sperm oil formerly used, and is also cheaper. It burns with a brighter flame and does not cause so much deposit on the wicks, which therefore burn much longer without requiring to be trimmed. It also requires far more intense cold to thicken it than other oils, and there is therefore much less need for the small auxiliary frost lamp used in frosty weather for warming the oil in the main lamp. The thickness of the wicks is another point to be attended to, as a thin wick gives a brighter flame than a thick one under the same circumstances. When a lamp is in proper condition, supplied with proper materials, and in the hands of a moderately careful attendant, the flame can be kept up for fully seventeen hours to its full size, untouched, without requiring to have the wicks trimmed. The quantity

of oil consumed in a dioptric light during a given period is thus to a certain extent a test of the efficiency of the light, as it indicates the height of flame kept up during that time.

The construction of the apparatus for producing the revolution in revolving lights is shown in Fig. 2, Plate 14, which represents a revolving light recently constructed by Messrs. Chance for Russia.

The revolving platform D carrying the optical apparatus is mounted on a large cast iron pedestal E, within which is placed the clockwork G for producing the revolving motion. The revolving platform D is carried on twelve gun-metal rollers HH, centered on a live roller frame I, running round a fixed centre shaft J on the top of the pedestal. The roller paths on the top of the pedestal E and the underside of the revolving platform D are of steel; and the rollers H are fitted on their spindles with washers of different thickness, to allow of slightly varying their positions from time to time, in order to avoid grooving the paths by running constantly in one line. The driving motion is communicated from the clockwork G by a pinion gearing into an internal toothed wheel K on the underside of the platform D. Formerly a simple spur wheel worked by the pinion was used, but it was found that the motion was never steady enough in this mode of driving, on account of the small number of teeth in contact and the backlash between them: but with an internal wheel the number of teeth in gear at a time is much greater, and the motion is rendered much more smooth and regular. The clockwork G is driven by a heavy weight, and the speed is regulated by a pair of flies on the flywheel L, which are adjusted to the proper angle for controlling the motion to the required speed. The whole of this improved arrangement of clockwork and pedestal was devised by Messrs. Stevenson of Edinburgh for the service of the Northern Lights, where its constant use for many years has proved its great superiority over the arrangements adopted in all other revolving lights.

The optical apparatus itself is of an octagonal shape, as shown in the plan, Fig. 4, Plate 15, and the frame is constructed entirely of gun-metal. The catadioptric prisms BB composing the upper and lower portions of the light are fixed in the eight gun-metal standards

of the frame; but the lenses **A** forming the central portion are carried in separate frames, bolted to the standards, with a slight clearance left at the top, to prevent the risk of any weight coming on the rings of glass forming the lenses, which being in close contact with one another would give way under the least pressure. At the bottom the prisms **B** are omitted in one side to allow of access to the lamp **C**, which is erected upon a stand on the service table, as shown in Figs. 1 and 2. A copper ventilating tube **M** extends up above the lamp into the neck of the cowl, Fig. 8, Plate 17, on the plan introduced into the lighthouse service by Professor Faraday. The inverted funnels **N** placed at different levels in the ventilating tube afford a free escape to any accidental downward gust of wind, and thus prevent any risk of the lamp being blown out; and it is found by experience that the wind may blow in suddenly at the cowl, but the effect never reaches the lamp. The draught of the heated air in the tube **M** also draws off through the funnels a quantity of the air of the lightroom, thereby preventing condensation of the moist air upon the glazing of the room, which would otherwise interfere greatly with the efficiency of the light. A short length of the tube at the bottom containing the damper **P**, Figs. 1 and 2, is made to slide upwards, to allow of removing the glass chimney, but so as not to weigh on the glass or fall when the glass is taken out.

The Lantern, within which the whole of the lighting apparatus is contained, is shown in Fig. 8, Plate 17. It is of an octagonal shape, as shown in the plan, Fig. 9, Plate 18, and is 13 feet diameter, formed of cast iron panels with the joints planed to the proper bevil so as to fit solid together. The standards **O** supporting the dome of the lantern and forming the framing for the plate glass panes are inclined alternately right and left, which adds greatly to the stiffness of the structure, while the light is not entirely intercepted in any vertical plane, as would be the case if the standards were vertical. The standards are of wrought iron, of a bevil section, as shown enlarged in Fig. 11, Plate 18; to prevent corrosion by the action of the sea air they are protected along the outer edge with a gun-metal facing **R**, grooved to receive the plate glass panes **S**, which are then

secured in their places by thin covering strips of gun-metal screwed on outside. Two sets of gun-metal astragals T, Figs. 10 and 12, to support the glazing are fixed horizontally between the standards, at the level of the joints between the refracting lenses and reflecting prisms of the optical apparatus, so as not to stop any of the rays emanating from the light.

The glazing S of the lantern consists of panes of plate glass about $\frac{3}{8}$ inch thick, the edges of which are ground and the arises bevelled to prevent breakage in fixing or in any possible shaking of the lantern in a violent gale. Small strips of lead are placed between the glass and the gun-metal frames, and the interstices are filled up with putty. The glass lies entirely within gun-metal frames, and there is no difficulty in replacing a broken pane at any time. To guard against an accidental stoppage of the light through breakage of a pane in a gale or by sea birds flying against the glass, storm panes are provided, made of a copper frame glazed with thick glass, which are kept always ready in the lightroom and can be fixed in a few minutes in place of a broken pane. The copper dome U, Fig. 8, Plate 17, forming the roof of the lantern, is made double, with an air space between; and the cowl V at its summit revolves with the weathercock, to turn the openings always from the wind, allowing a free escape for the heated air from the ventilating tube of the lamp.

The efficiency of a dioptric light depends entirely upon the proper adjustment of the various optical elements which compose it. The vertical divergence of the rays of light depends on the dimensions of the flame of the lamp, and seldom exceeds an angle of 5 degrees, which is amply sufficient for all practical purposes. For an angle of vertical divergence equal to one fourth of the dip of the horizon illuminates half the whole distance from the horizon to the lighthouse; and an angle of vertical divergence equal to the dip of the horizon illuminates three fourths of that distance. Within a mile or two from the lighthouse however an angle of vertical divergence equal to the dip of the horizon illuminates only a small fraction of a mile, showing how little is gained by increasing the vertical divergence at the sacrifice of brilliancy at the horizon. Thus for a tower of 100 feet height, about

1-6th of a degree ($9' 45''$) is the amount of the dip of the horizon, and a further angle of the same amount illuminates the sea from the horizon towards the land for a length of $8\frac{1}{2}$ nautical miles, the total range of the light being in this case $11\frac{3}{4}$ miles. For a tower of 200 feet height the dip is about 1-4th of a degree ($13' 46''$), and a further angle of the same amount illuminates from the horizon a distance of 12 miles out of a range of 16 miles. These figures show that a vertical divergence equal to the dip of the horizon is quite sufficient to illuminate the sea from the horizon up to within a moderate range of the tower.

The efficiency of the light depends also upon its being correctly adapted in direction and divergence to the particular elevation it is intended to occupy, otherwise a portion of the brightest rays may pass above the horizon and consequently be lost, instead of being of service at and within the horizon. The dioptric system also affords peculiar facility for directing the light upon any particular point where it is more especially required. For instance: a light may be required merely as a sea light, for the purpose of signalling to mariners their approach to the land; in that case the most intense light of the whole apparatus is directed towards the horizon. Or a light may be required to illuminate the horizon, but most particularly the sea in the neighbourhood of the land, the approaches of a harbour, or some particular local danger; in that case the light of some portions of the apparatus is directed towards the horizon, and the light of the other portions is deflected towards the point requiring special illumination.

A specimen of one face of the optical apparatus, containing the lenses and prisms of a revolving light, was exhibited from Messrs. Chance's glass works, and also a specimen of the pressure lamp used for the most powerful lights.

The CHAIRMAN enquired what were the particular difficulties with the mechanical lamps formerly used in lighthouses, in which the oil was raised by pumps driven by clockwork.

Mr. MASSELIN replied that the old mechanical lamps were complicated in construction, and the clockwork for working the oil pumps had to be got into a confined space, being more like watchwork than clockwork, and requiring a skilled mechanic properly trained to manage it; and as lighthouses were generally situated at a distance from any town, it was a serious objection to have any liability of requiring to send away to get the necessary repairs done. The pressure lamps now used were of simple construction and stronger in all the parts, as shown by the specimen exhibited; they had no machinery about them requiring attention and there was therefore no liability of the light ever failing from the lamp getting out of order. Of course clockwork was still required for making the lights revolve, but this was so much stronger and larger that it was not liable to get out of order, and admitted of easy repair.

The CHAIRMAN asked whether the wicks in the lamp were all used at the same level, and what height of wick was required above the burner.

Mr. MASSELIN said each wick was raised independently of the rest by a separate screw, and all were turned up to exactly the same level, standing about $\frac{3}{8}$ inch above the burner, of which about $\frac{1}{4}$ inch became blackened by the flame, leaving $\frac{1}{8}$ inch steeped in the overflow of oil standing above the burner.

The CHAIRMAN enquired how the burner was replaced in case of its ever being injured by overheating from the wicks burning down too low.

Mr. MASSELIN showed that the entire burner together with the glass chimney was readily removed by simply unfastening two screws, and it could then be immediately replaced by a fresh burner, which was kept always ready at hand in the lightroom; but such a case never

occurred in practice while the light was burning at night, because the supply of oil was maintained constantly greater than the consumption, ensuring an abundant overflow, which prevented the wicks from burning down to the burner. The light was now kept up with such regularity that the wicks did not require any alteration during the whole night, after having been once adjusted to the proper level for producing a brilliant flame.

The CHAIRMAN enquired how the lamp could be removed if required at any time after the optical apparatus had been fixed in its place.

Mr. MASSELIN replied that there was ample room for getting out the lamp through the space left by either omitting the bottom panel of prisms on one side of the optical apparatus or hanging it on hinges. In the old lamps in which the oil cylinder was made roughly of sheet brass and therefore not truly cylindrical, the piston had to be made a very loose fit and the cupped-leather large; and the piston being loaded with weights upon it was liable to get unequally weighted when the weights were changed, so that the piston was canted and the leather turned inside out, rendering the lamp useless and requiring the piston to be taken out for re-setting the leather. This defect caused a prejudice at first against pressure lamps: but in the new lamps with the cylinder cast and bored no such accident could occur; and they were so strongly constructed in all the parts that there was now no more occasion for providing a duplicate lamp cylinder than for providing a duplicate optical or revolving apparatus; but duplicates were provided of all the working parts of the lamp which were in the least likely to wear. The weight giving the pressure on the piston was suspended below the lamp, and could readily be increased or diminished according to the degree of fluidity of the oil in the cylinder, without disturbing the action of the lamp.

The CHAIRMAN asked whether any of the fountain lamps were still in use, and what arrangement was adopted for fixing the oil reservoir so as not to interfere with the light.

Mr. MASSELIN said the fountain lamps were not all abandoned yet, but they were being gradually replaced as they became worn out by more efficient lamps. There was generally one side of the lighthouse towards the land on which the light was less wanted than on the

others, and the oil reservoir was then placed on that side just at the level of the burner.

The CHAIRMAN enquired what distance the dioptric lights were visible, and whether the whole of the light was confined in the vertical direction within so narrow a limit as only 5 degrees of divergence.

Mr. MASSELIN replied that the range of the light depended on the height of the lighthouse and consequent distance of the horizon: at Lundy Island in the Bristol Channel, where the lantern was about 540 feet above the sea, the horizon was about 35 miles distant and the light was distinctly seen at that distance. The power of the light at such a distance depended of course upon the concentration of the greatest possible amount of the rays within a very small angle, and the angle of 5 degrees was the maximum amount of vertical divergence in most cases. The extreme minuteness therefore of the angles to be dealt with rendered perfect accuracy of workmanship and adjustment in the optical apparatus of the utmost importance. The middle ray or axis of the light did not issue in a true dead level, but was deflected to the horizon, being depressed by the amount of the dip of the horizon, so as to throw the strongest part of the light full upon the horizon; and of the $2\frac{1}{4}$ degrees or 150 minutes forming the lower half of the divergence, the first 10 minutes alone were sufficient to light three quarters of the distance from the horizon towards the lighthouse, in the case of a tower 100 feet high. If more of the light was wanted on the sea and less on the horizon, the axis was further deflected, so that the central rays fell on the sea nearer in than the horizon.

The CHAIRMAN asked what was the greatest distance for which reflecting lights were employed, and whether there were many of them now in use.

Mr. MASSELIN believed it was only in England and the English colonies that there were any lights remaining on the old reflecting system, as they had been entirely abandoned in other countries for dioptric lights, and in this country the present reflecting lights would no doubt be replaced by dioptric apparatus, as soon as the reflectors required renewal. He did not know what was the greatest distance illuminated by a reflecting light, but with a sufficient number of lamps and large reflectors there was no reason why as good a light should

not be obtained by the reflecting system, for revolving lights, as by the dioptric: but the cost of maintenance and consumption of oil was much greater in the reflecting system, and the whole of the reflectors required entirely renewing after a certain time of wear. The largest reflectors that he knew of were 21 inches in diameter, and the greatest number employed in any one light was from 24 to 30.

Mr. SAMPSON LLOYD thought the paper that had been read was of great value and general interest on account of the high degree of perfection attained in the apparatus, and also from the number of wrecks still occurring and the importance of efficient lighthouses for preventing them. He enquired what increase had taken place in the number of lighthouses since the introduction of the improved system of lighting, and how many dioptric lights there now were round the coast of England.

Mr. MASSELIN replied that eighty years ago there were no lighthouses deserving of the name, but only a few towers with coal fires to serve as beacons; and even as late as 1820 several of the main lights, at Harwich and elsewhere, were only open coal fires with a brass plate placed behind as a rude kind of reflector. The celebrated Eddystone lighthouse was originally lighted by only a few miserable tallow candles, and in 1780 the first reflectors were used; but these were made only of plaster of paris, hollowed to a parabolic shape, having the inner face covered over with small pieces of ordinary mirror glass set in the plaster, which were replaced in 1807 by copper reflectors silvered on the face. The old reflecting system continued in general use until 1834, when Fresnel's more perfect dioptric light was introduced into this country, the first being erected on Lundy Island. The optical apparatus then consisted of only the annular lenses forming the central portion through which the light was simply refracted, without any of the catadioptric or totally reflecting prisms by which the light was now rendered luminous throughout the entire height of the apparatus. The number of lights now in use round the coast of England was altogether about 200, of which only about 38 were dioptric lights; but in the United States there were already more than 500 dioptric lights.

The CHAIRMAN asked in what manner the prisms were adjusted to their correct positions in the optical apparatus, and whether that was done before the apparatus was fixed at the lighthouse.

Mr. MASSELIN regretted that Mr. J. Chance had been unexpectedly prevented from being present to afford explanation of the optical portion of the apparatus. The principle of adjustment was that each prism of glass in the apparatus was separately adjusted and fixed at the correct angle for the ray from a distant fixed point to be directed in each case to a focus where the flame of the lamp was situated, so that all the rays intersected at that focus, and the whole of the light from the lamp was consequently deflected into the required direction towards the horizon. The height that the light had to be fixed above the sea being given, the angle of dip of the horizon was known, and the whole of this adjustment could consequently be made in the works by having a staff erected at a distance as the object to be viewed in making the adjustment of the prisms, the staff being graduated by calculation to correspond with the true direction of the rays if prolonged to the horizon from each line of prisms. A sight was fixed in the focus of the apparatus at the point where the brightest part of the lamp flame was to be, and each prism was separately adjusted until the image of a white line on the vertical staff was correctly thrown into the focus, a separate line for each prism being marked upon a staff specially graduated for each apparatus, according to the intended elevation of the lighthouse above the horizon. The adjustment was formerly in a few instances made at the sea coast, but by this arrangement it was now done at the works with much greater facility. Owing to the flame of the lamp being not a single point but extending over a height of as much as 4 inches in the largest size, the central rays only could be actually directed to the intended point, and the rays from the upper and lower portions of the flame gave a total divergence of the light of about 5 degrees vertically. Formerly, and still in France, the prisms were all set to a dead level, and on account of the dip of the horizon the central ray was consequently thrown above the actual horizon, and more than half the light was lost by being thrown into the air, instead of upon the sea; but here each prism was treated separately, and set so that its central ray was depressed to the horizon or to a point somewhat

within the horizon, so as to throw the greatest intensity of the light where it was most wanted for vessels approaching from a distance, and to make the greatest proportion of the light available.

The CHAIRMAN asked how the prisms were bedded and fixed in the gun-metal frames.

Mr. MASSELIN replied that during the process of adjustment the prisms were held in their places by small wooden wedges; and as soon as the adjustment was completed, they were secured by a little plaster of paris at three points of each, which set quickly, and the remaining space was filled in afterwards with white and red lead putty: this set very hard in a few days, and held the prisms secure in their right position, and prevented them from touching the metal frame anywhere, otherwise the glass would soon get chipped.

The CHAIRMAN observed that very great accuracy must be required in the form of the prisms, to ensure the correct direction of the rays, as any error would be so greatly magnified by the long distance; and enquired how the prisms were shaped to their correct form, so as to ensure each being a true figure.

Mr. MASSELIN replied that the required accuracy of work was obtained by doing the grinding and polishing of the prisms entirely by machinery of accurate construction. The prisms were set on horizontal revolving tables, like a horizontal face plate of a large lathe, up to 11 feet diameter, the prisms of the same section and the same curvature being fixed on the same table in a continuous circular ring of the required diameter, and having one face bedded in plaster of paris; the two other faces were then ground and polished in their position by a set of rubbers with emery powder and rouge, worked transversely by machinery as the table revolved, and moving at the required inclination or in curves of the required radius.

Mr. W. MATHEWS, JUN., enquired whether any chromatic aberration in the light was produced by its passage through the glass, as in the refraction of light through ordinary prisms.

Mr. MASSELIN said no appearance of prismatic colours was noticed in the light, and if there were any it was so slight as not to be perceptible, probably on account of the resolved coloured rays from the different prisms being so completely intermingled by the vertical

divergence of the light as to reproduce the white light free from prismatic colours.

The CHAIRMAN considered they were much indebted for the clear and valuable information given in the paper on a subject of such general importance, in which such extensive interests were involved. It was most necessary that the greatest possible perfection should be attained in the lighting apparatus of lighthouses, on the constant efficiency of which so many lives and vessels had to depend for safety. He proposed a vote of thanks to Mr. Masselin for the paper, which was passed ; and also to Mr. James Chance for his kindness in lending the specimens exhibited.

The following paper was then read :—

ON THE COAL AND IRON MINING OF SOUTH YORKSHIRE.

BY MR. PARKIN JEFFCOCK, OF DERBY.

It is proposed in the present paper to consider the general features of the South Yorkshire district with reference to the circumstances affecting mining engineering.

The accompanying general plan, Fig. 1, Plate 19, represents that portion of the Yorkshire coalfield which is more particularly called the South Yorkshire district; extending from Sheffield on the south to Wakefield on the north about 25 miles, and from west to east about 20 miles altogether, on either side of Barnsley. The plan shows the general extent of the coalfield, indicated by the shaded portion; the outcrops of two of the principal seams of coal, the Silkstone and the Parkgate seams; the positions of the principal faults; the localities of the more important collieries and ironworks; and the lines of railway and water conveyance.

The horizontal section, Fig. 2, Plate 20, which is reduced from the late Mr. Thorpe's published section, is taken through Barnsley along the dotted line **WE** upon the plan, Fig. 1, extending from the millstone grit on the borders of Derbyshire on the west to the eastern boundary of the coalfield at **E**.

The vertical section, Fig. 3, Plate 21, represents the position and thickness of the principal beds of coal and mines of ironstone, as they were proved by borings at Wath Wood, near Lundhill Colliery on the plan, Fig. 1. Five beds of coal, between the Woodmoor seam and the Kent's Thin seam, do not occur at this place; a second vertical section, Fig. 4, is therefore placed alongside, showing these beds in their corresponding position as they were proved in sinking at the Oaks Colliery near Barnsley, Fig. 1.

The South Yorkshire coalfield is a continuation northwards of the Derbyshire coalfield. On the east it is bounded by the overlying and unconformable magnesian limestone and permian strata, and the extent of the coal measures in this direction is yet unproved. On the west the millstone grit rocks crop out, forming the bleak moors of North Derbyshire; and the coal measures extend northwards and constitute the North Yorkshire coalfield. The general dip of the coal strata is from west to east at an average angle of 1 in 9; this however is much modified in many localities by main faults, the principal of which are shown on the plan, Fig. 1, by the strong black lines. The total number of coal seams is very great, as shown in the vertical section, Fig. 3, and many of them have been worked in various localities.

The following are the principal seams of coal in their geological order, with their average thickness :—

1.	Wath Wood or Muck seam	...	...	...	4 ft. 6 ins. thick.
2.	Coal, no name	...	...	...	3 8
3.	Woodmoor seam	...	...	...	3 0
4.	Winter seam	...	...	...	5 4
5.	Upper Beamshaw seam	...	...	...	4 8
6.	Lower Beamshaw seam	...	...	...	2 2
7.	Kent's Thin seam	...	...	...	2 7
8.	Kent's Thick or High Hazel seam	...	...	...	5 0
9.	Barnsley Thick seam	...	...	8 ft. 6 ins. to	9 0
10.	Swallow Wood seam	...	...	...	5 0
11.	Howard or Flockton seam	...	...	...	5 0
12.	Fenton's Thin seam	...	...	...	2 3
13.	Parkgate or Chapeltown seam	...	...	...	6 9
14.	Thorncliffe Thin seam	...	...	...	2 6
15.	Four Foot seam, variable	...	...	...	4 0
16.	Silkstone or Sheffield seam	...	...	...	5 0
17.	Charlton Brook or Mortomley seam	...	...	...	3 0

The most important seam of the series is the Barnsley Thick coal, which under the name of the Main or Top Hard coal has been very extensively worked in Derbyshire. In the South Yorkshire district its average thickness is about 8 feet 6 inches, but the thickness varies exceedingly at different places. It is most fully developed in the neighbourhood of Barnsley, but extends through the greater part of

the district, and has been principally worked at Woolley, Gawber, The Oaks, Edmund's Main, Wombwell Main, Darley Main, Elsecar, Warren Vale, Rawmarsh, Hoyland, Lundhill, Mount Osborne, Thryburgh, Darfield, Car House, &c. The hard coal from this seam is in great repute for steam purposes, and stood high at the trials made at Woolwich in 1851 relative to the value of steam coals. North of Woolley the Barnsley seam is subdivided into two or three others, which are worked in the neighbourhood of Normanton under different names. In Derbyshire it appears to the best advantage at the large works of Mr. Barrow at Staveley, where it is known as the Staveley Hard coal, which has been extensively used for steam purposes and in the manufacture of iron.

The Swallow Wood seam occurs about 60 yards below the Barnsley Thick coal, its thickness varying from 3 feet 4 inches to 6 feet. It has been worked only to a very limited extent, principally at Swallow Wood; and is known in Derbyshire as the Dunsil or Oldgreaves coal, lying there about 30 yards below the Top Hard seam.

The Parkgate or Thorncliffe Thick seam occurs at an average depth of 219 yards below the Swallow Wood, and has been chiefly worked at Parkgate, Thorncliffe, Pilley, &c. Its average thickness is 5 feet 6 inches, but the thickness varies considerably from 4 feet 10 inches to about 6 feet. It is known as the Bottom Soft coal in Derbyshire, where it has been very extensively worked.

The Thorncliffe Thin seam, called the Bottom Hard in Derbyshire, is found 24 yards below the preceding; its thickness is from 2 feet 6 inches to 3 feet, and it has been principally worked at Thorncliffe, Pilley, &c.

The Silkstone or Sheffield seam lies about 61 yards below the Thorncliffe Thin, and has an average thickness of about 5 feet. It is a very well defined seam, and may be taken as a sort of datum line in identifying the position of the other beds. It has been principally worked in the neighbourhood of Sheffield, and at Chapeltown, Thorncliffe, Pilley, Mortomley, and Silkstone; and is identical with the Blackshale or Clod coal of Derbyshire. The coal is of great value for house fire purposes, competing with the celebrated Hetton Wallsend.

By far the most important and valuable of the seams of coal are the Barnsley Thick and Silkstone seams. At the Woolwich trials made by the admiralty in 1851 relative to the strength and value for steam purposes of the Barnsley Thick coal from Darley Main, West Hartley coal from Newcastle, and Welsh coal from Merthyr Tydvil, the total weight of water evaporated in each case was 24,960 lbs., and the evaporation per lb. of coal was 8·10 lbs. by the Barnsley Thick and West Hartley coals, and 8·25 lbs. by the Merthyr coal. Trials were also made of the Barnsley Thick coal in 1858 at Doncaster on the Great Northern Railway, when the evaporation obtained was 7·64 lbs. of water per lb. of coal, the total weight of water evaporated being 448,281 lbs., and the coal used being a mixture of steam coal and house fire coal consumed under Cornish boilers working at a pressure of 45 lbs. The Barnsley Thick coal lights easily, burns freely, and raises steam rapidly. It produces only a very small quantity of white ashes and cinders, giving little trouble to the stokers, and the less it is disturbed the better; it does not clog or adhere to the bars, and makes no slag, maintaining a good clear fire with little sulphur. It is a most economical coal for marine engines, and in using it a light thin fire is particularly recommended.

The mines of Ironstone occur between the Barnsley Thick coal and the Silkstone coal, as shown in the vertical section, Fig. 3, Plate 21.

The first mine of importance is the Swallow Wood, about 60 yards below the Barnsley Thick coal, which has been principally worked at Milton for the supply of the furnaces there. It consists of three measures of ironstone, and an analysis of a sample of the ore by Mr. Spiller of the Geological Museum gave 26·79 as the percentage of metallic iron.

The Lidgate mine, next below the Swallow Wood, has been extensively worked at Milton, Tankersley, and Thorncliffe.

The Tankersley mine is usually found about 50 yards below the Lidgate, and is called also the Musselband ironstone from the number of fossil shells it contains. It has been worked chiefly at Tankersley, and yields about 1500 tons of ironstone per acre.

The Thorncliffe Black mine lies about 70 yards below the Tankersley: it is worked principally at Parkgate, and used in the furnaces at Milton and Elsecar; and an analysis by Mr. Spiller gave 34·16 per cent. of metallic iron.

The Thorncliffe White mine lies immediately below the Parkgate seam of coal, and consists of three measures, containing about 32 per cent. of metallic iron and yielding about 1500 tons of ore per acre. It has been worked principally at Parkgate and Thorncliffe, and was formerly worked extensively at the Holmes.

The lowest mine is the Clay Wood or Black mine, consisting of three measures, containing about 32 per cent. of iron and yielding about 1600 tons of ore per acre. It has been got to a great extent at Thorncliffe, and is identical with the Black Shale or Stripe Rake of Derbyshire, which is so much prized by the ironmasters of that county.

The principal ironworks of the South Yorkshire district are at Parkgate, Holmes, Milton, Elsecar, and Thorncliffe, in blast; and at Chapeltown and Worsborough, out of blast.

The modes of working the coal in the South Yorkshire district may be considered as modifications of the "long wall" system so extensively and successfully practised in the midland counties. The "pillar and stall" mode of working adopted in the north of England has not been much used in South Yorkshire; and the "long wall" system being principally confined to the midland counties, the South Yorkshire system of working may be regarded as a combination of the two. Where the circumstances are favourable, the "long wall" system is being extended in the Yorkshire coalfield; and wherever it can be adopted it is to be recommended on account of the simplicity of arrangement both for working and ventilation, and also as being the most economical method of getting the coal.

The principal modes of working the coal adopted in Yorkshire are the "Narrow Work," "Long Work," "Bords and Long Work," "Wide Work," and "Bank Work." These are shown in the ideal diagrams, Plates 22 to 27, the first five of which have been prepared from diagrams kindly lent for the purpose by Mr. Charles Morton, the government Inspector of mines for Yorkshire. They can be represented

only by ideal plans, because none of them are carried out in their integrity at any collieries in the South Yorkshire district; and in some instances one mode is adopted in one part of the workings and another elsewhere in the same colliery. These different systems of working, some of which however are falling into disuse, have been rendered necessary by the variable nature of the roofs and floors of the coal seams in the South Yorkshire district. The same reference letters are used throughout all the diagrams.

Fig. 5, Plate 22, is a plan of the mode of working by "Narrow Work," on the end of the coal. P is the downcast pit, and B the main "bord" (road cut transversely to the grain of the coal, against the "face" of the coal), from which pairs of "headings" or "endings" E E (roads cut against the "end" of the coal, lengthways of the grain) are driven at intervals of about 30 yards. When these endings have been carried to the requisite distance on either side of the main bord B, a communication is made between their extremities, and the coal is worked by short faces homewards, as shown at W W. The whole of the coal being thus got out, the roof is allowed to come down in the goaf as the working progresses, being temporarily kept up immediately behind the working faces by props or puncheons, which are afterwards withdrawn successively and shifted forwards. U is the upcast shaft, and F the ventilating furnace. The main current of fresh air from the downcast pit P is carried up the main bord B and along the furthest pairs of endings E, as shown by the arrows, and is then passed through the face of the workings W. The course of the air is determined by stoppings S built to block up the various crossgates between the bords and endings; and by doors D, through which the coal is brought down to the shaft from the workings W, and from the endings E that are in process of being driven. At C is an air crossing, where the current of foul air proceeding from the workings to the upcast shaft U crosses over the current of fresh air entering the mine from the downcast pit P. At R R are regulators to control the quantity of air passing through each portion of the mine; when these are closed, the whole of the fresh air has to pass through the workings before reaching the upcast shaft; but when they are opened, a portion of

the air finds a shorter course through the regulators direct to the upcast shaft, and a smaller quantity of air therefore passes through the workings. This mode of working is falling into disuse in Yorkshire, and is seldom adopted except under special circumstances, where the coal is of a soft or friable nature and where the roof is not strong, the coal being therefore got in very short lengths, as shown at W W, with only a very "narrow" face in process of working at a time, whence the name of this mode of working.

There are two modes of "Long Work," the first of which is shown in Fig. 6, Plate 23. This and all the subsequent modes of working are on the face of the coal, the workings W being carried forwards transversely to the grain of the coal, against the "face" of the coal, instead of against the "end" of the coal as in the previous "narrow work." In Fig. 6 it will be seen that there is a long face of work in progress at once in each portion of the mine: the workings are started from the main headings or endings E, and the coal from the working faces is brought down through the goaf by means of packed roads G, shown by the strong black lines, the walls of which are built up of rock and shale; the packed roads are carried forwards continuously as the working faces advance. The fresh air from the downcast shaft passes along the endings E and the packed roads G up to the working faces W, and thence by the bords B to the upcast shaft U, as shown by the arrows, the regulators R R controlling the ventilation in each portion of the workings. At H H are doors or stoppings with apertures to allow of passing some of the air through the packed roads G in the goaf, according as may be required to keep them clear of gas.

In the second mode of "Long Work," shown in Fig. 7, Plate 24, the workings are subdivided into separate lengths of face by the pillars L being left between them at first, about 30 yards thick; but when the workings have been carried forwards as far as intended, the intervening pillars are then also worked, beginning from the further end and working backwards, as seen at A, whereby the current of air is always kept up against the pillar face A until the whole pillar is removed. The packed roads G are required for bringing out the coal

through the goaf in this plan of working, the same as in the first mode of "long work;" the strong dotted lines through the goaf in the neighbourhood of the pillar working A show packed roads that are no longer required to be maintained and have been abandoned. The course of the air is shown by the arrows.

The mode of working by "Bords and Long Work" is shown in Fig. 8, Plate 25. Here pairs of bords B B are driven from the main heading or ending E, at intervals of about 20 yards; and when they have reached the extreme distance intended, the whole of the intervening coal is worked homewards, downhill, and is brought out from the working face W through the bords B. In "bords and long work" therefore the bords form a marked feature in the system, being driven to the extreme extent in the first instance, as shown in the right-hand half of the plan, Fig. 8, before the working of the whole coal is commenced; and when this has been begun, as shown in the left-hand half of the plan, no packed roads are required in the goaf for bringing out the coal from the working face, but the coal is brought down through the bords themselves, which are thus not obliterated till all the coal is won, but remain of service to the last. In the previous modes of "long work" on the contrary, shown in Figs. 6 and 7, the progress of the work is in the opposite direction, uphill, and the face of work is opened without driving bords; and accordingly packed roads are required to be maintained through the goaf for bringing down the coal from the working face. The course of the air is shown by the arrows in Fig. 8, and the air regulator is placed at R; but in "bords and long work" there is no need of any arrangement for coursing part of the air through the goaf, as is required in "long work."

In the "Wide Work" method, shown in Fig. 9, Plate 26, the coal is got in banks W about 60 yards long, each subdivided into bords 7 or 8 yards wide, separated by pillars of an average thickness of one yard, as shown by the thick black lines in the goaf. Crossgates K are made to the main roads B at suitable intervals, according to the state of the atmosphere in the mine and the ventilation. For ventilating the workings the current of air is passed up the furthest bord B, across the face of the work in the first bank W, and out at the other

end of the bank; it is then carried forwards up the intervening pillar bord B to the next bank, and across the working face in the same manner, as shown by the arrows. This method of working is now being abandoned where possible for the "long wall" system.

In the "Bank Work," shown in Fig. 10, Plate 27, the coal is got in banks W about 60 yards long, as in the last mode, but each bank is worked all in one length without any intermediate pillars being left in each bank. The method of ventilation is the same as in "wide work," as shown by the arrows. The mode of working by single bords B, as in both "bank work" and "wide work," instead of by pairs of bords, is however to be condemned on account of the difficulty and expense of maintaining packed roads through the goaf for the winning of the pillars BB at the last; or if they have not been maintained, of making new packed roads for ventilation: and again these pillars being liable to a heavy pressure, the coal in the pillar working is rendered of little value.

The plan of the "Long Wall" system of working, Fig. 11, Plate 28, shows the difference of this system from any of the ordinary Yorkshire methods of working described above. This is not an ideal plan, but a plan of the actual "long wall" workings of the Parkgate seam at the Wharnccliffe Silkstone Colliery near Barnsley, Fig. 1. There is here no loss in getting out pillars, as all the coal is excavated at one operation. The ventilation of the mine is at the same time considerably simplified, the current of air having altogether a shorter and less tortuous course to follow from the downcast shafts P to the upcast U, as shown by the arrows. The thick dotted line MM shows the position of a fault in one portion of the mine, and the workings are therefore laid out at that part conformably with the course of the fault. By the "long wall" system a working face of 430 yards is here obtained in a single length without interruption, as shown at W; and in the lower portion of the workings along the fault MM another face has been opened of the same total length but divided into two shorter faces by a pillar bord, for safety and convenience of working in the neighbourhood of the fault, the intervening pillar being removed before that portion of the mine is abandoned.

Various supports for the roof are used in the Yorkshire seams: wooden props or puncheons are adopted in some cases; in others piles of wooden blocks called "chocks" or "clogs," and in others "packs" of rock and shale. Cast iron puncheons also are now being extensively introduced, one of which is shown in Figs. 17 and 18, Plate 29.

Two of the greatest difficulties that have to be contended with in mining are Water and Gas. With regard to Water, the mines in the South Yorkshire district are not in general heavily watered in comparison with other mining districts; the workings nearer the outcrops or "bassets" of the seams are generally more watered than the rest. Except in some special instances there are few collieries where large pumping engines are required: lift pumps are used exclusively, and even tubbing has scarcely ever been resorted to. A remarkable inundation occurred a year ago at the Woolley Colliery at Darton near Barnsley, Fig. 1, which is working the Barnsley Thick coal: the coal is drawn up a long inclined plane extending from the outcrop of the Barnsley Thick seam and following the dip of the seam; and the water is raised by means of flat pumps. On the 13th April 1861 a sudden irruption of water into the workings took place, to such an extent that they were almost entirely filled. The water entered through a fissure in the overlying rock, which is of considerable thickness and is full of cracks and fissures towards its outcrop. It is probable that a large amount of head or drainage water had accumulated in these fissures while they remained closed, and that they afterwards became opened by subsidence of the strata in consequence of the working of the coal: the water was found to be drawn away from a well in the rock at the surface 170 yards above the coal. The accumulation of water must have been very great, as it continued rising in the day drift a fortnight after the inundation had occurred, at the rate of more than 1 foot per hour, although a double 10 inch pump had been kept continuously at work; but its rise was subsequently stopped by additional pumping power.

In the amount of Gas generated by the different seams of coal there are great variations. The most terrible explosions have taken place in the Barnsley Thick coal, especially at the Darley Main

Colliery, the Oaks, Warren Vale, and Lundhill: the Barnsley Thick and Silkstone seams being specially liable to sudden and powerful emissions of gas. The ventilation is produced by a furnace, shown in Figs. 12 to 15, Plate 29, situated at F in the diagrams, Plates 22 to 28, at the bottom of the upcast shaft U, by which a fresh current of air is kept continuously flowing through the mine, so that any gas issuing from the coal is speedily diluted and rendered harmless. For distributing the air through the workings, the stoppings S, doors D, and regulators R are arranged in proper places. The division of the air into separate "splits," each of which ventilates a distinct portion of the workings by means of the crossings or "overcasts" C, and the "scale doors" or regulators R, may be considered, if properly carried out, one of the best preventives of explosions in these very fiery South Yorkshire mines. All the return air should be conducted into the upcast shaft by a dumb drift N, Figs. 12 to 16, so as not to pass through the fire of the furnace; and the underground furnaces, whether closed or otherwise, should be fed with nothing but fresh air direct from the downcast shaft.

At some of the mines in the district, belonging to Earl Fitzwilliam, large fans driven by steam power have been substituted for the furnace generally used elsewhere; they are a simple and efficient means of mechanical ventilation, well worth the consideration of all interested in mining, and have now been continuously working with complete success for several years. In the early periods of mining the only ventilation was the natural ventilation, the current of air through the workings being produced simply by the colder and denser air from the downcast shaft displacing the hotter and rarer atmosphere of the mine. Sometimes rarefaction was increased by putting a pan of coals in the upcast shaft; but the consequence of such imperfect ventilation was that the workings were sometimes stopped for many days together. Natural ventilation could of course be adopted only when the shafts were of moderate depth and the workings on a limited scale.

The introduction of safety lamps into mines is of comparatively recent date. In the South Yorkshire district they were first used exclusively at the Oaks Colliery, in the workings of the Barnsley

Thick coal, where Stephenson lamps are used in preference to Davys ; and the use of safety lamps has since extended to many other collieries. At the Wharnccliffe Silkstone Colliery near Barnsley, working the Silkstone seam, Stephenson and Davy lamps are used exclusively ; and as the coalfield is very much cut up here with faults, the gas cannot be "bled" away, but as each fault is cut through the greatest caution is required in dealing with the gas in the solid coal beyond, "in bye." In addition to the use of safety lamps, an abundance of air should be taken into the working places of fiery mines. Since the explosion at Lundhill in 1857 safety lamps have been exclusively adopted there. The importance of their use in fiery workings was strongly shown at the Oaks Colliery in 1857, when an outburst of gas took place in the workings down the engine plane, so violent that it was compared to the roar of a draught in the furnace. All the Stephenson lamps were put out, and the Davy lamps were ignited internally, the gauze becoming red-hot. As the outburst of gas occurred within a hundred yards of the main intake to the upcast shaft, and a large quantity of air was passing this part at the time, the gas was soon diluted and carried away ; and in less than an hour the only traces that remained were found at one or two places where the floor had been upheaved. Thus no doubt a terrible explosion had been averted by the use of safety lamps ; but if any one of the lamps had been out of order, or the gauze smeared with oil or coal dust, or if any naked light had been in this part of the workings, an explosion would inevitably have occurred.

In conclusion it may be remarked that the facilities already existing by railway and canal communication for the conveyance of the minerals raised in this district to London and other markets, which in a few years will no doubt be considerably increased by the extension of the railway system,—and the central situation of the district in the great midland coalfield, the largest in England,—together with the extent to which it yet remains undeveloped,—combine to give the South Yorkshire district an important position among the mining districts of this country.

The CHAIRMAN enquired what were the principal differences in working the coal by the long wall system and by Yorkshire bank work, and what was the proportionate increase of yield per acre in long wall working.

Mr. JEFFCOCK replied that in the Yorkshire bank work, as shown in the diagram, Plate 27, a number of single "bords" (roads cut against the face of the coal, transversely to the grain) were driven following the rise of the coal; and at right angles to them a series of "endings" (roads driven lengthways of the grain, against the end of the coal) were cut into the intervening coal, which was then worked out, with the exception of a certain thickness left on each side of the bords to serve as pillars for supporting the roof over the bords, in order to keep them open for getting the coal out and maintaining the ventilation. The great difficulty in the bank work was in maintaining the ventilation properly up to the working faces while they were being pushed on into the solid coal beyond the last pair of endings opened, before the next ending was reached, as shown at WW on the plan; because at this time the working face was out of the direct line of the current of ventilation, and the air could not be efficiently kept close up to the workings. There was also a great loss in the quantity of coal that had to be left in the mine in the pillars; and if these were afterwards got out in a second working, the cost of working them was very great, and the coal itself was so much crushed as to be greatly deteriorated in value. But in the long wall system now being adopted, as shown in the plan of the long wall working at the Wharfedale Colliery, Plate 28, all second working to get out pillars was avoided, the whole of the coal being worked out at one operation. The yield of coal per acre was therefore much greater in the long wall mode of working, and its value was increased by the diminution in the quantity of small coal and slack produced by the working: there was also less expense in running the few long headings required in long wall working than in driving the great number of shorter ones required in bank work. Moreover the working face was always in the line of the ventilation, without any blind recesses into which the air would not enter; and the current of air passed along the entire face of the workings throughout its whole length.

Mr. W. MATHEWS enquired what was the comparative cost of getting the coal by these two modes of working.

Mr. JEFFCOCK replied that the cost of getting would be about the same at the working faces in each case ; but the total cost including "dead" charges was greater in bank work than in long wall work, on account of the expense of driving so many more passages in the former plan.

Mr. J. E. SWINDELL remarked that the larger amount of "dead" work on the roads in bank work must of course increase the cost of opening the mine ; and the long wall system appeared much superior in requiring fewer roads for winning the coal. It was also less expensive to cut a few gate roads of large size than a great number of smaller roads. He asked what length of face was being worked on the long wall plan at the Wharnccliffe Colliery shown in the diagram.

Mr. JEFFCOCK said the working face at that colliery was 400 yards in a continuous length, and the second face in the nearer portion of the workings was also of the same length, but subdivided by a pillar bord into two lengths : the total length of face was therefore 800 yards working on the long wall system.

Mr. J. E. SWINDELL supposed there would be a limit to the length of face that could be worked on the long wall plan, depending upon the quantity of coal that could be conveniently brought down the main gate roads at one time. He enquired whether the coal from the whole of the 400 yards working face was got out into the main gate roads through the single opening at each end of the face, or whether intermediate gob roads or packed roads were maintained through the goaf for conveying the coals got from the middle portion of the working face. If packed roads had to be maintained for this purpose, it would diminish the superiority of the long wall system as compared with other modes of working in respect of cost.

Mr. JEFFCOCK said in opening a new face of work the coal was brought out through the intermediate packed roads into the main gate road ; but as the working face was carried further forwards, they were gradually abandoned and the roof allowed to fall in, their outer ends next the gate road being closed by stoppings to preserve the ventilation. To save the expense of keeping these packed roads in

repair, new top levels were driven in the solid coal at the distance beyond which the packed roads would not carry without greater expense; and the pillars were afterwards got out along the sides of the levels. At the Wharnccliffe Colliery there were three main gate roads, worked as self-acting inclines, down which the whole of the coals from the two faces of work were brought to the winding shaft.

Mr. W. MATHEWS asked what was the inclination of the gate roads.

Mr. JEFFCOCK replied that they were driven according to the inclination of the coal, so as to be worked as self-acting inclines, the dip of the coal being 1 in 12.

The CHAIRMAN observed that it was very important to get as much large coal as possible, and undoubtedly more large coal could be got by a long face of work than by a short one. He enquired how far this result had been obtained at the Wharnccliffe Colliery.

Mr. JEFFCOCK said the size of the coal got depended upon its structure, and the Parkgate seam worked at the Wharnccliffe Colliery on the long wall system was of a cubical structure, easily breaking up short in working, so that the long wall system did not give so much advantage in this instance in yielding the coal large. But coal of a long fibrous character, like some of the Derbyshire coals, could be worked very large without difficulty.

Mr. J. E. SWINDELL asked whether the long wall system was equally applicable for soft coal as for hard.

Mr. JEFFCOCK replied that the long wall system was equally suitable for both, the only difference in the mode of applying it being that the hard coal was worked "on the face" (the workings being carried forwards transversely to the grain of the coal), while the soft coal was generally worked "on the end." With coal of cubical structure however it mattered little which way the coal was worked, and at the Wharnccliffe Colliery the working was on the face of the coal.

Mr. J. E. SWINDELL enquired what was the cost of getting the coal by the long wall system.

Mr. JEFFCOCK replied that the cost of getting alone was about 1s. 5d. per ton, exclusive of winding power, plant, sinking the shafts, sending out or conveyance of the coal underground, and making and

maintaining the roads: but the rate of labour in South Yorkshire was nearly 15 per cent. in excess of other colliery districts.

The CHAIRMAN asked how the "deep" coal was won from the lower side of the shaft; whether a second shaft was sunk for the purpose. He supposed in laying out the colliery the pit would be planted in such a position as to win the coal as much as possible to the rise.

Mr. JEFFCOCK said the winning of the deep coal involved an underground engine for hauling it up to the pit bottom, or else the ropes must be sent down the shaft from an engine on the surface; and a flat pump worked by the engine must be put down for drainage, following the dip of the coal. But if the coal was much watered it was better to sink a second pumping shaft for draining the deep coal, and the same shaft could then be used also for winding if required.

The CHAIRMAN enquired where the flat pumps were principally used, and what was the extreme length through which they had been worked.

Mr. JEFFCOCK said the flat pumps were mainly used near the outcrop of the coal, at collieries worked by an adit, for draining workings in the deep when there was not much water. At the Woolley Colliery at Darton near Barnsley, which was worked by an adit from the outcrop of the Barnsley Thick coal following the dip of the seam, the flat pump extended a long length, from the outcrop to the furthest extremity of the workings, and was a double plunger pump with working barrels 10 inches in diameter. On occasion of the inundation at this colliery, mentioned in the paper, the second flat pump was put down for clearing the pit, the pump barrel being gradually moved forwards as the water lowered.

The CHAIRMAN asked whether the pump trees were of wood, and only the working barrel and suction nozzle of iron.

Mr. JEFFCOCK replied that the pump trees were ordinary castings, and only the spears were of wood, working upon rollers at one side of the adit: the pumps were ordinary plunger pumps delivering the water through a cast iron pipe extending to the mouth of the adit, or to a level that might be cut through the measures to intersect the adit.

Mr. W. MATHEWS said that at Clough Hall Colliery near Stoke-upon-Trent a flat pump was used for a distance of 100 yards following the dip of the coal at an inclination of 1 in 4 or 5, and it was about being extended to 200 yards: the pump trees and working barrel were of cast iron.

The CHAIRMAN enquired what was the weight and cost of the cast iron puncheons or props used for supporting the roof, and whether they were always managed to be got out of the mine again without loss. In some of the Staffordshire pits where they had been used, the difficulty had been to get them all out again.

Mr. JEFFCOCK showed a full size model of one of the cast iron puncheons, 3 feet 9 inches high, and said they were made to suit the height of the seam, weighing from $\frac{1}{2}$ cwt. to 1 cwt. each, and costing from 4s. to 6s. each. They were given out to a set of men whose sole business was to attend to the fixing of them and moving them forwards as the workings advanced; and were required to be delivered up again whole or broken, otherwise the men were debited with the cost of those missing. The men were well used to the work, and generally managed to get all the puncheons out safely and without loss: on withdrawing the hindmost row of puncheons in the goaf the roof did not generally fall in immediately, but some interval elapsed before it came down, allowing time for the men to get all cleared away; in the neighbourhood of faults however there was more danger, and great caution was then needed.

Mr. J. E. SWINDELL asked how many of the cast iron puncheons were used in a mine.

Mr. JEFFCOCK said sometimes as many as 3000 or 4000 cast iron puncheons were used in a single mine, costing therefore from £800 to £1000.

The CHAIRMAN enquired whether the saving had been clearly ascertained of using cast iron props instead of wood. This was a question of great importance at the present time; for when such a large number of props were required in a single mine, the extensive adoption of iron props if found advantageous would afford an opening for the use of iron in colliery workings.

Mr. JEFFCOCK could not give the actual comparative cost of cast iron and wood props, but understood the cast iron puncheons had been found decidedly advantageous where used, and preferable to wood props. The use of cast iron however depended altogether on the nature of the roof and floor of the mine; where either of these was soft, an iron puncheon was of no use, as it would go in like a skewer.

Mr. J. MURPHY asked what was the cost of timbering the mines in the South Yorkshire district per ton of coal raised.

Mr. JEFFCOCK replied that at collieries raising a good quantity of coal the cost of timbering amounted on the average to about 1*d.* per ton of coal raised.

Mr. J. MURPHY asked whether that cost included timbering the roads. In South Wales the cost of props was generally reckoned at 3*d.* or 4*d.* per ton of coal raised, including timbering the main roads, at collieries raising 600 to 800 tons per day.

Mr. JEFFCOCK said the cost of 1*d.* per ton of coal was only for the timber props supporting the roof at the working faces, which were moved forwards after each day's work; but if the gate roads required timbering the cost would of course be much greater. Most of the packed roads however through the goaf were built up with bind or shale from the roof and not timbered.

Mr. W. P. BEALE knew of two pits working in the same seam of coal, one with wrought iron props and the other with wood, and understood the cost was decidedly in favour of the iron props. One of the pits was at Messrs. Beale's Colliery at Scholes near Chapeltown, in the Parkgate coal, where the wrought iron props had been used since the commencement of the working about eight years ago: the iron for the props was rolled of a cross section, about $4\frac{1}{2}$ inches width each way and $\frac{5}{8}$ inch thickness in the ribs (see Figs. 19 and 20, Plate 29), which was cut into the required lengths of about from 4 feet to 7 feet to form the props; a flat circular cap was then welded upon each end, and a ring shrunk on in the middle for convenience in pulling out and prizing the props. The other pit using wood props was the Newbold Colliery near Chesterfield, where the same seam was worked under the name of the Potter's coal; but the roof at the

former pit was much harder than at the other, allowing the wrought iron puncheons to be employed advantageously. Similar wrought iron props had also been used for the last ten years in Earl Fitzwilliam's pits at Elsecar and Parkgate, working the Barnsley Thick coal of about 7 feet thickness.

The CHAIRMAN enquired how much coal could be drawn per day out of one pit with the long wall system, in the Silkstone or the Parkgate seam, with a total working face of 800 yards length.

Mr. JEFFCOCK said in reference to the Silkstone seam it could not be worked in such a long face as 800 or even 400 yards, on account of the tender nature of the roof. But as regarded the general question of the quantity of coal that could be got by the long wall system, he thought the real limit must be considered to be the engine power for raising the coal; for by extending the length of working face and increasing the number of men, enough coal could always be got to employ the whole engine power available. As a case of actual working however the Oaks Colliery near Barnsley might be named, working in the Barnsley Thick coal, where 600 tons per day were now being regularly drawn by one winding engine, and sometimes as much as 800 tons per day : both shafts were used for winding, and were about 250 yards deep. It was at this colliery that safety lamps were first used exclusively in the district, the men having previously believed it impossible to work entirely with safety lamps, but this had now been done regularly ever since their first introduction there; and it was a fact worthy of notice that the large quantity of 600 to 800 tons per day was worked entirely with safety lamps, proving that the use of them did not involve any interference with the rate of working.

The CHAIRMAN enquired whether gas was employed for lighting in any of the collieries.

Mr. JEFFCOCK said it was not used in any of the collieries in the South Yorkshire district.

He explained that the paper was originally intended to be ready for the meeting at Sheffield in the previous year, in order to be read in the district to which it belonged, but he had been unexpectedly prevented from getting it ready then.

The CHAIRMAN considered the paper instead of being at all out of place in now being read and discussed in the Staffordshire district was the more acceptable, for it was only by the communication of such information from one district to another that improved modes of working could be introduced and greater economy arrived at : he was sure the information now given about the South Yorkshire coalfield would be highly appreciated in the Staffordshire district. Valuable opportunities were thus afforded by the meetings of the Institution for extending the experience of the members, and he believed advantage was always derived from the papers read and the information elicited in discussion. He proposed a vote of thanks to Mr. Jeffcock for his paper, which was passed.

The following paper was then read :—

DESCRIPTION OF A FEED-PIPE CONNEXION FOR LOCOMOTIVE ENGINES.

BY MR. ALEXANDER ALLAN, OF PERTH.

Various constructions of Feed-pipe Connexion between locomotive engines and tenders have been used at different times; but the double ball-and-socket plunger pipes, made of brass, are most generally applied, in order to have a continuous metallic connexion, allowing of blowing steam through into the tender without injury. These however are very expensive, requiring great nicety of fitting and much care in their management in work; and, in consequence of sand and dirt getting in at the moveable parts, they involve a serious outlay for maintenance, and in practice it is almost impossible to keep them perfectly tight, while if the joints be too tightly screwed up there is risk of the feed-pipes breaking.

To obviate these defects and obtain a continuous metallic connexion comparatively inexpensive both in first cost and maintenance, and combining simplicity, durability, and efficiency, the writer has substituted the connexion shown in Figs. 1 and 2, Plate 30, consisting of a simple brass or copper tube A, coiled to a circle of considerable diameter, so as to have sufficient elasticity to allow for the vertical disturbance due to the unequal deflection of the engine and tender springs, and also for the extreme lateral range required in going round the sharpest curves, with a minimum strain on the joints. A solid-drawn brass tube is employed, varying from No. 17 to No. 14 wire-gauge in thickness or $\cdot 060$ inch to $\cdot 085$ inch, coiled to a circle of 3 feet to $3\frac{1}{2}$ feet diameter, as shown in Fig. 2.

In order to offer less resistance to bending, the tubes are made elliptical in section, about $2\frac{1}{2}$ inches deep by $1\frac{1}{2}$ inch broad, as shown full size in Fig. 4, Plate 31. Tubes of circular section 2 inches in

diameter, as shown full size in Fig. 5, have also been used, but they are more rigid than the elliptical tubes. Experiments have been made to ascertain the amount of force necessary to stretch and compress the coiled tube and also to deflect it vertically and laterally through the extreme range required in practice; and the results show that the elliptical tube has the advantage in elasticity, the first inch of deflection requiring only about 30 lbs. pressure, while a total pressure of from 90 to 100 lbs. is sufficient to produce the extreme deflection of about 3 inches in any direction; up to this pressure there is no permanent set and consequently no fear of the tube collapsing in any part. The experiments have been extended with the elliptical tube up to $3\frac{1}{2}$ inches movement in any direction, giving a total range of 7 inches, up to which the tube may be strained safely; beyond this limit a permanent set is produced. In practice however the total range in any direction never exceeds 5 inches, or $2\frac{1}{2}$ inches on each side of the central position, leaving a sufficient margin of elasticity to prevent injury to the tube. With a thinner tube or one coiled to a larger circle an increased range could be obtained if desired.

The connecting tube A is attached to both engine and tender by means of the ordinary screw and tail pipe couplings BB, Figs. 1 and 2, Plate 30, the tail pipes being brazed upon the circular ends of the tube, as shown in the section, Fig. 3, Plate 31. It is placed above the axle and suspended to the foot plate by short chains C, as shown in Fig. 1, so that the wheels can be removed without interfering with the feed-pipe connexion, and it is less liable to damage should the engine get off the rails than the ordinary ball-and-socket couplings. The connecting tube is placed central in the engine whenever practicable, so that the angular deflection produced in running round curves is reduced to the minimum; but it can be fixed without any practical objection in the usual side position of the feed-pipe, as shown in the plan, Fig. 2, so as to admit of ready application to existing engines and tenders. Figs. 1 and 2 show the connexion applied to an engine fitted with an injector D for supplying the boiler; and the dotted lines E show the end of the tube when a pump is used.

This connexion has been fitted to a number of locomotives on the Scottish Central Railway, including some large goods engines; and it has been subjected to severe tests during the last twelve months, and has given every satisfaction. In the engines on this railway the plan of coupling between the engine and tender, drawing as well as buffing on a heavy laminated spring, allows more movement than is usual, amounting to a play of 2 inches between the engine and tender, and the connecting tube is 6 inches out of the centre; but even under these conditions no failure of the connecting tube has occurred. The dimensions of the engine to which it has been longest attached are: diameter of cylinder 16 inches, stroke 20 inches, driving wheel 6 feet diameter, steam pressure in boiler 130 lbs. per square inch, and boiler supplied with one No. 9 injector; and the connecting tube has now been continuously working upon this engine for nearly twelve months with complete success, the engine having run about 20,000 miles during the time. This tube has been taken off the engine and is now exhibited to the meeting: it is of circular section and simply secured with soft solder, and there is not the slightest sign of its giving way, showing that it is fully equal to its work. A specimen is also exhibited of a connecting tube of oval section, used on large coupled engines: in its manufacture the tube is swaged oval in proper crasses, and is then filled with resin and coiled to the required circle round the cast iron blocks used for blocking tyres.

The CHAIRMAN regretted Mr. Allan had been unexpectedly prevented from being present.

Mr. SAMPSON LLOYD believed a somewhat similar plan of coupling had been tried on the South Western Railway, but did not know whether it had been successfully carried out on that line.

Mr. D. JOY thought the new coupling was the best connexion he had seen, and much superior to either the ball-and-socket coupling or the flexible hose pipes.

The CHAIRMAN enquired what was the cost and durability of the ordinary hose pipes.

Mr. D. JOY said the flexible hose pipes of canvas and india-rubber were the simplest connexion, and cost only about 7s. 6d. each; but their durability was very uncertain; they lasted twelve months with proper care if made of good material, but sometimes failed in a single month. He thought the coupling now shown seemed as good in simplicity and was much superior in durability; and it had an advantage in being placed close up under the foot plate, where it would be out of the way of injury if the engine got off the rails.

Mr. J. MURPHY suggested that an iron tube might be used, as cheaper than brass or copper.

Mr. D. JOY thought the extra cost of the brass or copper tube would be saved in the manufacture, from the greater ease of manipulation compared with iron, the total weight of metal being so small; an iron tube would also be more rigid, while the greater elasticity of brass or copper would increase the durability of the coupling.

The CHAIRMAN moved a vote of thanks to Mr. Allan for his paper, which was passed.

The Meeting then terminated.

PROCEEDINGS.

1, 2, AND 3 JULY, 1862.

The ANNUAL SPECIAL MEETING of the Members was held in the Lecture Theatre of the Royal Institution, Albemarle Street, London, on Tuesday, 1st July, 1862; Sir WILLIAM G. ARMSTRONG, President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected :—

MEMBERS.

ROBERT ANGUS,	Stoke-upon-Trent.
HENRY BECKETT,	Wolverhampton.
CALEB BLOOMER,	Westbromwich.
NELSON BOYD,	Hartington.
JOHN FARMER,	Dudley.
SAMUEL GODFREY,	Middlesborough.
WILLIAM J. W. HEATH, . . .	Birmingham.
PETER EMILE HUBER,	Zurich.
JOSEPH KNOTT,	Leigh.
JOHN LLOYD,	Wellington, Salop.
HUGH MCPHERSON,	Gloucester.
FRANCIS C. MIERS,	Broadstairs.
JOHN MILLWARD,	Stourbridge.
JOHN R. RAVENHILL,	London.
JOHN SILVESTER,	Westbromwich.
WILLIAM THOMPSON,	Newcastle-on-Tyne.
JULIAN HORN TOLME,	London.
RICHARD WATKINS,	London.
PERCY G. B. WESTMACOTT, . .	Newcastle-on-Tyne.

The PRESIDENT then delivered the following address :—

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ADDRESS OF THE PRESIDENT.

The annual meeting of the Institution in the present year occurs under circumstances of peculiar interest. The metropolis in which we are assembled has for a while become the centre of the civilised world; and the Great Exhibition which marks the period of our meeting is an event of real moment in the history of nations. This year's gathering of our Institution is therefore of a somewhat special nature; and I believe that by directing the remarks which I have again the honour to make to you from this chair chiefly to the subject of the International Exhibition of 1862, and particularly to that portion of it which comprises the works of Mechanical Engineers, I shall act most in accordance with your wishes and the spirit of the occasion. I am the more induced to do so from the circumstance that the first of these large annual meetings of the Institution was held in London during the former International Exhibition, on which occasion the late lamented Robert Stephenson was your President.

In commenting upon the present Exhibition it is impossible to abstain from some reference to its precursor of 1851. Unhappily the retrospect is a sad as well as a fitting one; for we can never forget that the chief difference between the Exhibitions of 1851 and 1862 is that over the latter there has been thrown a shade of mourning. The author of both Exhibitions saw his first work finished, and enjoyed its well earned fruits; but he has not been spared for the completion of his later task. We engineers, of all men, should lament the death of the Prince Consort, whose exalted rank never blinded him to the true dignity of labour. Though he favoured science in every branch, as well in the abstract as in its practical applications, yet he showed an evident preference for those scientific pursuits which lead to

tangible results ; and we may feel sure that he would have rejoiced as heartily as any of us at the progress in mechanical engineering which is so strongly marked in the present Exhibition. Had he lived, the disparaging criticisms upon the Exhibition which have from time to time been made would probably never have been heard. If it were necessary to relieve any class of exhibitors from the false charge of mere commercial display, in no case would it be easier to do so than in that of the mechanicians. For my part I find it hard to account for the enterprise, the courage, and the self-sacrifice of the many exhibitors both from this and other countries, who, from a mere sense of the obligations imposed on them by their position in their respective callings, or from purely public spirit, have by a great effort and at a most unremunerative expenditure rendered the mechanical department in the Exhibition perhaps the most interesting and the most valuable of all. The mere association of the Prince's name and his early labours in connexion with this very Exhibition should save it from any unworthy imputations, and recall those noble principles and considerations which he has told us were the motive and origin of all international displays. Let me remind you of the words in which he first announced the objects of the former Exhibition at the banquet given by the Lord Mayor in March 1850 to the mayors of nearly every corporate town in the kingdom. "Nobody," said he on that occasion, "who has paid any attention to the particular features of our present era will doubt for a moment that we are living at a period of most wonderful transition, which tends rapidly to accomplish that great end to which indeed all history points,—the realisation of the unity of mankind: not a unity which breaks down the limits and levels of the peculiar characteristics of the different nations of the earth; but rather a unity, the result and product of national varieties and antagonistic qualities." "Science," he continued, "discovers the laws of power, motion, and transformation. Industry applies them to the raw matter which the earth yields us in abundance, but which becomes valuable only by knowledge. Art teaches us the immutable laws of beauty and symmetry, and gives to our productions forms in accordance with them." "Gentlemen," he said, "the Exhibition of 1851 is to give us a true test and living

"picture of the point of development at which the whole of mankind has arrived in this great task, and a new starting point from which all nations will be able to direct their future exertions." Such were the Prince's words on that occasion, and they apply with equal force to the present Exhibition.

It seems to me that the most striking characteristic of International Exhibitions is that they define epochs in the continuous course of industrial progress, and render the advance attained in each period appreciable by reference to the preceding. Another attribute is that in each Exhibition the deficiencies of every contributor are brought home to himself with a force which no other means could exercise, and the strongest possible stimulus is in this way given to individual exertions. Thus in 1851 every contributor saw for the first time his own products placed side by side with those of competitors from all parts of the world, and was irresistibly made aware of his own shortcomings. The new Exhibition shows how far the contributors have understood the lessons they received ten years ago, and to what extent they have learnt and profited by them. No doubt the schooling which the English exhibitors had in 1851 was chiefly upon points of taste: yet it was not without application to subjects within the field and province of engineering, and I think we shall be ready to say that engineers have decidedly gained something from the Exhibition of 1851, and that the proof is afforded by the Exhibition of 1862.

There is one remarkable distinction between the two Exhibitions which I am peculiarly called upon to notice. Most of us may remember to have seen in the first building one or two field guns, which were generally thought to be out of place and inconsistent with the character and object of the whole display. In the present building we all know that arms and armour are predominant. Besides rifled artillery there are rifled small arms, together with armour plates and beautiful models of iron plated ships, all of which represent war, and make up a very formidable portion of the British share in the Great Exhibition. Yet this prominence of warlike material will not lead us to the conclusion that peace is endangered. The cannon may be a grim associate of peace, and yet be her best security and support.

Without it we should lie at the mercy of all the world, a tempting bait to every marauder. Our wide spread commerce and vast wealth both at home and abroad require all the protection we can give; and it is of vital importance that in guarding them we should be possessed of weapons of the highest efficiency. We may be glad therefore that the implements of war have not been excluded from the present Exhibition, more especially as they show the direction in which some of our best and most successful industrial efforts have lately been made.

Already the great struggle between guns and armour plates has proved of value even for the direct purposes of peace. It has instigated improvements in the fabrication of iron, which must prove beneficial to the productive manufactures of the country. I will instance the great exploits in rolled and forged iron achieved by the Mersey Steel and Iron Company, Messrs. Brown and Company of Sheffield, the Butterley Company, and the Coalbrook Dale Company, all having reference more or less to armour plated ships. These unusual efforts arising out of the contest between the powers of offence and defence lead the way to peaceful developments and adaptations. The armour plates have to be carried by ships of enormous strength and size. The ships involve in their construction the manufacture of rolled beams and forged cranks of dimensions and patterns such as are seen in the eastern annexe, and such as at the period of the last Exhibition would have been deemed wholly impracticable. For the propulsion of these ships marine engines are required of extraordinary power, and for their armament the skill of the mechanic is taxed to the utmost to provide guns of commensurate strength and efficiency. These efforts made in the interest of war extend the limit of our manufacturing attainments, and thus ultimately benefit the cause of peace and commerce.

In my last address I alluded to the importance of obtaining a material which should combine the toughness of wrought iron with the homogeneous character of a cast metal; and I then referred to Mr. Krupp of Essen as having taken the lead of all British manufacturers in the art of producing steel forgings of extraordinary dimensions. The specimens which Mr. Krupp has sent to the present

Exhibition justify all that I said on that occasion, and present examples which from their soundness and magnitude excite the wonder and will stimulate the rivalry of English steel makers. I fear however that it must be admitted that, notwithstanding the great advance which has been made in the manufacture of steel, we have not yet procured this material in a form which is adapted for the resistance of concussive action. All attempts to use steel for the purposes of armour plates have shown its inferiority to wrought iron; and since the qualities necessary for resisting the impact of a shot and the explosion of gunpowder seem to be identical, I am still of opinion that, whatever the future may produce, we have as yet no material equal to wrought iron for the manufacture of ordnance.

I should extend these remarks beyond suitable limits were I to attempt any detailed notice of the many interesting objects contained in the mechanical department of the Exhibition. I will therefore conclude by expressing a hope that the progress which has been made in mechanical engineering during the last ten years may suffer no diminution during the next decennial period; and if another Exhibition should arise at the end of that time, may it compare as favourably with the Exhibition of 1862 in the department of mechanical engineering as the present Exhibition compares with that of 1851.

A vote of thanks was passed to the President for his address, on the motion of Mr. C. P. Stewart seconded by Mr. C. Greaves.

The following paper was then read:—

ON SURFACE CONDENSATION IN MARINE ENGINES.

BY MR. EDWARD HUMPHRYS, OF DEPTFORD.

The subject of Surface Condensation in steam engines, especially in marine engines, was first brought to the notice of the writer in 1833 by the proceedings of Mr. Samuel Hall, then of Basford: and it is more with the view of drawing attention to the success with which this system was practised a quarter of a century ago, than of describing any new combinations possessing advantages over the plans then adopted, that this paper is submitted to the meeting; indeed nearly the whole of the practical details about to be given were published fully twenty-seven years ago.

The writer's brother, the late Mr. Francis Humphrys, was employed by Messrs. John Hall and Sons of Dartford to design the engines made by them for the paddle-wheel steamer "Wilberforce" of 280 nominal horse power; and the writer thus had the opportunity of witnessing the designing, manufacture, and working of the surface condensers fitted to these engines. Drawings of the engines are given in "Tredgold on the Steam Engine", together with indicator diagrams taken from them in 1838, one of which is shown in Fig. 15, Plate 35; and up to the present time the writer is not aware of any better vacuum having been produced. He started these engines the first time they were set in motion, in the year 1837; and has a distinct recollection of the admirable manner in which the condensers did their duty. The vessel was employed between London and Hull until 1841, when the outsides of the condenser tubes having become very thickly coated with mud from the Thames and Humber, the tubes were removed and injection was substituted.

About fourteen years ago, when the writer held the appointment of engineer-in-chief of Woolwich dockyard steam factory, he had a second opportunity of obtaining practical information as to the working

of Hall's surface condensers, from the "Grappler" which returned to Woolwich after a three years' commission abroad, having been fitted with the surface condensers by Messrs. Maudslay Sons and Field. The floats of the paddle wheels were reefed, in order to allow the engines to work at full speed at moorings, and indicator diagrams were taken which showed that the performance of the condensers was quite satisfactory, and equal to what it had been before the vessel left this country. Owing to the defective state of the hull of the ship, the engines and boilers were taken out, and the latter were found in excellent condition, indeed almost as perfect as when first put on board. The engineers reported that the condensers had given very little trouble, and on examination they were found free from any defects. These and other examples of surface condensation with which the writer had become acquainted caused him to have great confidence in the system, and to desire to introduce it again at the earliest opportunity.

In 1859, having to design and construct a set of engines of 400 nominal horse power for the Peninsular and Oriental Co.'s new ship "Mooltan", with the view of trying what economy could be effected in the working of the machinery of their vessels, the writer determined to employ surface condensation, not expecting to realise any large amount of economy from this system alone, but believing that a great benefit would result from the increased durability of the boilers, and the saving of the time frequently lost in cleaning them, together with some economy of fuel arising from the absence of the necessity of blowing out. The practice of blowing out is indeed frequently carried to excess: in one instance known to the writer, at least four times the quantity of water necessary to keep the boilers clean was blown out, the expenditure of fuel being consequently most excessive.

Figs. 1 and 2, Plates 32 and 33, show very nearly the arrangement of the condensers of the "Mooltan"; and they show correctly the condensers now making by the writer for the Peninsular and Oriental Co.'s new ships "Mysore" and "Rangoon" of 400 nominal horse power. The area of surface in the condensers and in the boilers of all the three ships is almost identical: the boilers contain 4800 square

feet of heating surface in each ship, and the condensers of the "Mysore" and "Rangoon" contain 4712 square feet of condensing surface, and those of the "Mooltan" 4200 square feet. The indicated power of the "Mooltan" when tried officially was 1734 horse power; hence the area of condensing surface per indicated horse power is rather less than $2\frac{1}{2}$ square feet.

For convenience of manufacture and arrangement of these engines, the condenser of each is divided into two parts AA, Fig. 1, Plate 32, each part being exhausted by its own air pump B, Fig. 2, Plate 33, so that each pair of engines is provided with four air pumps and four condensers. The air pump B is 18 inches diameter with a stroke of 3 feet. These dimensions being used by the writer with injection condensers in engines of the same nominal power, he believes they are larger than necessary for surface condensers of engines in good condition, with condensing water at the average temperature of the sea in this climate; but as these engines are to be employed in the Indian seas, it was considered expedient to provide large air pumps and large pumps for circulating the condensing water, so as to allow of almost any quantity of condensing water being driven through the condensers that may be found necessary in an Indian climate. The air pumps B discharge their water direct into the boilers through the pipe C, according to Hall's plan, so that no feed pumps are necessary. The air which leaks into the engines is allowed to escape by an open stand-pipe connected to the highest point of the feed pipe, and carried up inside the mast, which is of iron, to a greater height than is due to the pressure of steam in the boilers. A valve regulated by a float was originally fitted to the "Mooltan" for allowing the escape of the air; but it was found to require some little attention, and hence the stand-pipe was substituted which answers perfectly without any attention.

Each condenser AA, Figs. 1 and 2, contains 1178 seamless drawn pure copper tubes, $\frac{5}{8}$ inch outside diameter and No. 18 wire-gauge or .050 inch thick, 5 feet 10 inches long, weighing 28 oz. each tube, and fixed at 1 inch pitch centre to centre, as shown full size in Figs. 3 and 4, Plate 34. The tube plates of the "Mooltan" are of cast gun-metal $\frac{3}{4}$ inch thick; but those of the "Mysore" and

"Rangoon" are of rolled copper, finished $\frac{3}{4}$ inch thick, one of which is exhibited. These are first set as flat as possible, and the tube holes marked out upon them. The holes are then drilled under a common drilling machine with a drill of two diameters, shown half full size in Figs. 7 and 8, Plate 34, having a guard D upon it to fix the depth to which the larger diameter shall penetrate the plate. One machine worked by an ordinary driller drilled the 1178 holes in the tube plate exhibited in 70 hours. The tapping of the holes is then proceeded with, and is effected with a tap, shown half full size in Figs. 9 and 10, having a parallel end E to guide it, which fits the smaller diameter of the tube holes. One man of ordinary skill tapped the 1178 holes in the plate exhibited in 70 hours. After having been drilled and tapped the tube plate is again set perfectly flat on a surface plate, and then both sides are faced off in a lathe or planing machine.

The screwed glands FF, Fig. 3, Plate 34, for securing the packing at the ends of the tubes, are made from Muntz' metal solid-rolled tubes, which are obtained in lengths of about 5 feet, rolled to gauge both inside and outside; the inside diameter is exactly that of the outside of the copper tubes, namely $\frac{3}{8}$ inch, and the outside diameter is such that when screwed it will exactly fit the tapped holes in the tube plates. It is screwed on the outside as it comes from the maker in a common screwing machine, as shown full size in Figs. 5 and 6, and is then cut by a circular saw into half inch lengths to form the glands. The saw marks are taken off the ends by a facing cutter revolving in a lathe, shown half full size in Figs. 11 and 12, and the same operation clears out the inside of the hole. The notch for the screwdriver is cut by passing a number of the glands, when screwed into a plate, under a revolving circular saw of the required thickness. The packing is composed of linen tape; a piece of this tape 12 inches long and $\frac{1}{16}$ inch wide is wound round a mandril, the ends and edges being slightly stitched, in which state it is readily put into the tapped holes of the tube plate, and when screwed down by the gland forms a very perfect and lasting joint. The thickness of the tape is such that 1000 of these packings weigh about 2 lbs.

The exhaust steam from the engines passes down through the interior of the condenser tubes, and the sea water for keeping the tubes

cold is driven up through the spaces between the tubes. The sea water is admitted through an inlet pipe fitted with a slide valve at the bottom of the ship, and enters the condensers at the bottom by the pipe G, Fig. 1, Plate 32: it then circulates round the outsides of the tubes, and makes its exit through the regulating valves HH at the top of the condensers, at about the load water line of the vessel. The valves HH answer the purpose of regulating the flow of sea water equally through the two divisions AA of the condenser, and also of shutting out the water from above when the outsides of the condenser tubes have to be examined. The flow of water is produced by one of Appold's centrifugal pumps, the diameter of the revolving disc being 36 inches; it is driven by a pair of wood and iron spur wheels, the proportions of which are about 1 to $3\frac{1}{4}$, so that at the ordinary speed of the engines of the "Mooltan", namely 56 revolutions, the pump makes 194 revolutions per minute. Two of these pumps are provided, the second being driven by an auxiliary engine to be used in case of the failure of the other.

The condensers constructed according to the proportions and mode of manufacture above described and adopted by the writer have been found quite efficient and very durable. The indicator diagrams, Figs. 13 and 14, Plate 35, taken from the "Mooltan" in a voyage in October of last year, show the degree of exhaustion in the cylinders, which are 96 inches diameter and 3 feet stroke, the steam being exhausted into them from the high pressure cylinders of 43 inches diameter and the same length of stroke: the boiler pressure was 17 lbs. per square inch. The engines were making 58 revolutions per minute, and the diagrams show that the vacuum in the cylinders was sufficient to support a column of mercury 26 inches high when the vacuum in the condensers was 28 inches of mercury.

The condensers of the "Mooltan" have now run 42,000 miles: and at the end of 30,000 miles, namely in April last, the writer examined the inside and outside of the condenser tubes, and found the outsides perfectly clean; but inside there appeared a slight coating of grease resulting from the lubricating material employed in the interior of the engines. This was however so slight as not to affect the action

of the condensers; indeed the vessel ran the last 800 miles of the 30,000 at an average speed of 60 revolutions per minute with 24 lbs. steam in the boilers, and the vacuum in the condensers supporting a column of mercury $27\frac{1}{2}$ inches high. A very careful examination of the inside of the boilers showed that the action of the surface condensers, returning always pure water into them, is likely to ensure their continued efficiency, as there was no appearance of deterioration whatever. The lubricating material employed in the engines collects in the boilers, adhering to the sides and stays about the water line, and is to be found in large lumps in the bottom water space below the furnaces: this requires to be taken out occasionally, otherwise in the opinion of the engineer in charge it causes the boilers to prime.

Before determining on adopting exactly Hall's mode of manufacture for the condensers, although his experience of it had been very favourable, the writer examined the other plans for surface condensation, in most of which the joints between the tubes and tube plates are made with vulcanised india-rubber; but having understood that a chemical action took place between the copper of the tubes and the sulphur employed in preparing the india-rubber, and not being able to discover in the new plans any advantage over Hall's condenser, he adhered to this construction in the condensers of the "Mooltan." As regards the action of the vulcanised india-rubber on the copper tubes, the writer placed a piece of copper tube inside a piece of vulcanised india-rubber tube, and carefully washed and weighed the copper tube every month, and found a gradual decrease in its weight.

In designing the engines of the "Mooltan" no provision was made for cleaning either the insides or the outsides of the tubes of the condensers, except that the connexion between the condensers and cylinders was so arranged as to admit of the ready removal of the entire condenser case with its tubes. Each condenser case is a rectangular vessel about 2 feet 10 inches by 3 feet 6 inches and 5 feet 10 inches high, as shown in Figs. 1 and 2, Plates 32 and 33; and by removing the bolts in the joints I and K at top and bottom the entire condenser with its tubes can be drawn out clear of the cylinder, and the inside of the tubes can then be cleaned, the tube plates being in this case of gun-metal cast with the edge thickened $\frac{1}{4}$ inch

all round on the outer face, so as to clear the projecting glands of the tube ends. The two condensers of one engine might be removed, the tubes cleaned, and the condensers refixed in 40 hours; but up to the present time there is nothing in the state of the condensers to indicate the necessity of cleaning either the insides or outsides of the tubes; indeed the outsides are cleaner and brighter than when the tubes were first fixed in their place. When it becomes necessary to clean the insides, it is recommended to apply a solution of caustic soda by filling the condenser with it up to the top of the upper joint I; this was also the practice followed by Hall with success in his condensers in 1837. Indeed Hall's condensers were employed in the "Penelope" for more than six years, and the engineer in charge during that period stated that, with the exception of occasionally cleaning out the insides of the tubes by the application of a solution of soda and water, the condensers never gave an hour's trouble. The cost of a sufficient quantity of the solution to clean out the condensers of a 400 horse power engine would be about £5; and it is possible that it may be found desirable to perform this operation once a year.

The loss of water that occurs in the boilers from leakage and other causes is made good by an auxiliary boiler, the steam from which is passed through a small engine which pumps the water for supplying the hydraulic apparatus employed in steering the ship and other purposes, whereby the coal consumed in the auxiliary boiler is utilised.

Mr. HUMPHRYS showed some of the solid-drawn copper tubes used in the condensers, and one of the copper tube plates containing 1178 holes at 1 inch pitch, drilled and tapped; also specimens of the screwed glands and tape packings, and of the tools used in making the holes of the tube plate, as described in the paper.

He remarked that the whole condenser was of simple construction, the metal tube for making the glands being obtained rolled to size, so that it required only screwing in a common screwing machine, and

then cutting into half inch lengths to form the glands. By screwing down the gland sufficiently, the end of the copper tube was even indented slightly all round by the pressure of the packing, as seen in the tube exhibited, so that the ends of the tube could be really fixed in this way: in practice however one end of the tube was left free, to allow of expansion and contraction. The condenser was made essentially the same as it had been made twenty-five years ago by Mr. Hall, and he believed was a very perfect apparatus. In the condensers he was now making, the outsides of the tubes could be washed through pretty readily, as the centrifugal pump employed to drive the cold water through the condenser could also be made to work like a bilge pump for drawing the bilge water out of the ship; and by then taking off the cover of the side hole at the bottom of the condenser a considerable current of water could be sent through, so that if any dirt should accumulate at the bottom, in consequence of the condenser having been employed in dirty water, it would be all removed by the rapid current of water. Up to April last however, when the "Mooltan" had run 30,000 miles, no dirt had accumulated in the condensers.

The CHAIRMAN enquired the reason of the failure of former attempts with Hall's condenser, and why it had gone out of use.

Mr. HUMPHRYS did not consider there had been any failure in the former trials of Hall's condenser, but believed it had been really successful from the time when first tried thirty years ago. The great prejudice however at the time against any change from injection condensers had prevented the use of this surface condenser being persevered in; and objections had been raised to its use which the present experience had now fully proved were not attributable to the principle of the condenser.

Mr. J. F. SPENCER observed that he had also been working for many years at surface condensation, but on the opposite system of pumping the cold water through the interior of the condenser tubes and condensing the steam on the outside; and he was glad now to learn the practical results of the working of Hall's condenser in a large ship, as described in the paper, the merits of that condenser having certainly not been fully appreciated. He thought they were

much indebted to Mr. Humphrys for having brought forward the subject, and for the valuable record of facts contained in the paper that had been read.

In making a comparison between the two plans of surface condensers—the one with the condensing water outside the tubes and the steam inside, and the other with the steam outside and the water passing through the inside of the tubes—it was not necessary to consider either the space occupied by the condenser or the mode of making the joints at the ends of the tubes: because the space occupied depended entirely on the size of tube employed, and the same size might be adopted whether the water passed through the tubes or whether it passed outside; and the manner of making the joints by means of packings and screwed glands, as described in the paper, which was certainly a clever construction, might be adopted for any plan of condenser. Setting these considerations aside therefore, he considered an important practical difference between the two systems lay in the circumstance that in order to examine a single tube of a condenser on the construction shown in the drawings, with the water outside the tubes, it was necessary to break a vacuum joint; and if such a joint were made again defectively at sea in a hurry, air would leak in, the vacuum in the condenser would be diminished, and the efficiency of working impaired. Whereas when the water was inside the tubes, all the ends of the tubes were accessible by simply breaking a water joint, which was a matter of little consequence; for if this joint were made defectively at sea, the only result would be a small outward leak of water out of the condenser, which would not affect the working of the engines in the slightest degree. In this respect therefore he thought a real practical advantage attended the plan of passing the water through the inside of the tubes.

A better distribution of the water through the condenser was also obtained by the same plan of passing it through the tubes instead of outside. In the condenser shown in the drawings, with the water outside the tubes, he thought it would be almost impossible to pass the water thoroughly and equally over every portion of the condensing surface; whereas with the water inside the tubes, by dividing the whole quantity of water into three or four currents distributed equally

throughout the condenser, and by proportioning the area of the tubes to that of the pump, the water might be driven over every portion of the condensing surface with almost complete uniformity. This he considered a very important point, and attributed to it much of the condensing power possessed by condensers having the water inside the tubes, with which he had obtained a condensation of 12 lbs. of water per hour per square foot of condensing surface, which he believed would be found greatly in excess of the general result. For judging of the efficiency of a condenser, the main point to be ascertained was the weight of water condensed per square foot of condensing surface per hour, in order to know how much heat had been abstracted from the steam per square foot of surface, without any regard to either the nominal or the indicated horse power of the engine; and the condensation of 12 lbs. of water per square foot of surface per hour was the result he had obtained in work actually done in the "Sentinel," a vessel fitted with one of his surface condensers having the water inside the tubes, and working on the east coast of England. He enquired what was the amount of condensation per hour per square foot of condensing surface in the "Mooltan."

Two vessels of 400 nominal horse power had now been working nearly two years in the Canadian mail service between Liverpool and Quebec, the "Hibernian" and the "Norwegian," which he had fitted with the surface condensers having the water inside the tubes; and they made the voyage to Quebec and back, indicating 1200 horse power, on a consumption in one voyage of 32 tons of coal per day. In this case however the expansion was very limited, and there were circumstances which prevented the economy from being carried out as would be wished; and in two other similar boats of 400 nominal horse power now building for the same line he hoped a better opportunity would be obtained for showing the advantages of surface condensers.

With reference to the use of vulcanised india-rubber for making the joints at the ends of the tubes, and its effect on the copper tubes, he had now upwards of 50,000 of these joints working, a great many of which had been working for several years; and out of that number there had been but three cases of deterioration of the copper tube

from the action of the india-rubber, and in each of these cases the deterioration arose simply from defective fitting. Where there was a stream of hot salt water passing between the india-rubber and the copper tube, there corrosive action took place; but that was the result of defective workmanship. In all the rest of these joints, not a single case of the kind had occurred. He had lately had some of the tubes removed that had been working in condensers sixteen or eighteen months, and there was not the slightest appearance of deterioration. It was important to have so complete an answer to any objection on that score, because india-rubber was a very convenient material to use for any kind of joint, adapting itself by its elasticity to almost all conditions.

Mr. F. J. BRAMWELL enquired what was the degree of vacuum in the condenser at the time when the condensation of 12 lbs. of water per square foot of surface per hour was being obtained; because the amount of condensation varied with the vacuum that had to be maintained. He enquired also what was the proportion between the condensing surface and the boiler surface.

Mr. J. F. SPENCER replied that in the "Sentinel" which he had referred to, of 100 nominal and 350 indicated horse power, the vacuum in the condenser was 25 inches of mercury at the time of condensing 12 lbs. of water per square foot of surface per hour. The boiler surface was 1750 square feet, and the condensing surface 850 square feet, or practically one half of the boiler surface, which was the proportion he had generally adopted, giving in this case $2\frac{1}{2}$ square feet of condensing surface and 5 square feet of boiler surface per indicated horse power. Sometimes he had employed rather less condensing surface; but in no case had he made it exceed 3 square feet per indicated horse power, reckoning the boiler surface at about 6 square feet per indicated horse power or about 22 square feet per nominal horse power. In the "Hibernian" and "Norwegian" the boiler surface was 6200 square feet and the condensing surface 2700 square feet, being $5\frac{1}{2}$ and $2\frac{1}{2}$ square feet respectively per indicated horse power.

With regard to the accumulation of grease in the condenser, that was one of the reasons why he preferred the plan of having the steam

outside the tubes; for he believed it would be found that a condenser with the steam outside the tubes would last three times as long, with the same accumulation of grease, as one with the steam inside the tubes. It was evident that the accumulation would take place much more rapidly inside the tubes, and that the speed of passage of the steam would be much more retarded with each additional layer. He had had one condenser working about three years without any cleaning at all, the tubes being horizontal with the steam outside, and found that three fourths of the condenser was perfectly free from grease, and the remainder had only a small portion on the upper side of the tubes, the lower side being perfectly clean. A practical conclusion however could not be drawn from one or two cases; for at the first starting of a new plan great care was taken to obtain a satisfactory result, by using no more grease in the engine than was absolutely necessary for lubrication; but when a large number of condensers were at work, they would be subject to the usual casualties and want of attention at sea: grease might accumulate in the boilers and condensers, and would accumulate more rapidly he thought in Hall's condenser than in condensers with the steam outside the tubes.

The CHAIRMAN observed that the proportion between the boiler surface and the condensing surface that had just been described was as two to one; whereas the areas in the case given in the paper were 4800 square feet of heating surface and 4712 square feet of condensing surface, or practically the same.

Mr. HUMPHRYS said it must be borne in mind that in this case the 4800 square feet of heating surface in the boilers gave only 12 square feet per nominal horse power or $2\frac{1}{2}$ square feet per indicated horse power, instead of 6 square feet of boiler surface per indicated horse power as had been mentioned; and a comparison could not be made between different cases without taking into account the proportion of boiler surface per horse power. As regarded the quantity of water condensed per square foot of condensing surface, no experiments had been made; but the proportion of the condensing surface to the indicated horse power was $2\frac{1}{2}$ square feet per indicated horse power.

In reference to examining and cleaning the condenser tubes, this could be done in the condensers of the "Mysore" and "Rangoon" by taking off the manhole doors shown in the drawing immediately below the condenser. There was a height of 6 feet from the underside of the lower tube plate to the bottom of the water chamber, allowing room to stand upright inside, below the condenser, and with a rod the whole of the tubes could then be sponged out in a short time. A similar manhole door in the steam chamber above the condenser allowed of getting in to make good any tube joints at the top that might fail. He had however found the joints made as described in the paper remain good already for six years with ordinary brazed tubes: the tubes in the condensers of the "Mysore" and "Rangoon" were solid-drawn tubes, like the specimen exhibited, with which the joints could be made steam-tight with still greater certainty.

The CHAIRMAN asked whether any wear of the tubes had been observed, or any corrosive action.

Mr. HUMPHRYS replied that he had not found any wear or corrosion of the tubes whatever, and the condensers had not given the slightest trouble in any way. The cost of the tape packings for the tubes was very small and they were obtained at 16s. per thousand, ready coiled for putting in their places on the ends of the tubes.

Mr. T. HAWKSLEY was glad to find that the great merits of Hall's surface condenser were so fully acknowledged in the paper that had been read; he was intimate with Mr. Hall at the time of this invention, and thought it was much to be regretted that the inventor, after making a large fortune by other inventions, had been ruined almost entirely by this particular one. His surface condenser was introduced in only a few instances, and in each case had been removed again after being some time at work. The construction was exactly as had been described in the paper; and the reason why the condenser was objected to was for the most part that the tubes were found to clog with grease, so that the condensation became slow; and although the means were simple enough for cleaning the tubes, by employing some alkaline solution that would combine with and remove the grease, yet nothing of that kind being then attempted the

condensers did not act efficiently, and on that account were abandoned. In the next place the boilers accumulated oil, and the oil became decomposed into a thick gluey or tarry substance, which after being kept for some time in the boilers became like a piece of india-rubber, and got into a semi-elastic state: this substance settled down upon the plates and kept the water off the surface, so that the plates were burnt. Moreover the oil, before it had become decomposed, searched out every little defect of rivetting and closing of seams, and caused corrosion to take place at that part, so that boilers which had not leaked before began now to leak. These effects were attributed to the introduction of the surface condensers, rather than to defective workmanship; and the condensers themselves were accordingly removed. The coating of the tubes with grease and the effect upon the boilers of the introduction of grease into them were the only two objections that could be raised against the system of surface condensation, and he believed they could be removed by the use of an alkaline solution as had been described.

In respect of the proportion of the condensing surface to the horse power of the engine, Mr. Hall used 2800 square inches or nearly 20 square feet of condensing surface per nominal horse power, a much larger proportion of surface than had now been mentioned. When the tubes were clean and that proportion of condensing surface was used, the vacuum was formed very quickly; but when a smaller surface was used and the tubes became at all foul, then the condensation, although at the end of the stroke very perfect, was much smaller at the commencement, so that the mean vacuum formed during the whole of the stroke was much less than by the ordinary process of water injection.

Mr. G. A. EVERITT remembered Mr. Hall's endeavouring nearly twenty years ago to obtain solid-drawn copper tubes for his condensers; and thought the failure of the condenser might be partly due to the want of solid-drawn tubes, like that now exhibited, which were not made at that time.

Mr. HUMPHRYS did not think the failure of the early condensers could be attributed to the want of solid-drawn tubes, because the tubes in the present condensers in the "Mooltan" were like those used by

Mr. Hall, brazed tubes such as could be got thirty years ago, and similar to the tubes used in the condensers of the "Wilberforce" by Mr. Francis Humphrys twenty-seven years ago.

Mr. G. A. EVERITT remarked that brazed tubes were made better at the present time than twenty or thirty years ago. He enquired how long the condensers in the "Mooltan" had been in use.

Mr. HUMPHRYS replied that the condensers in the "Mooltan" had now been in use nearly two years, and had proved perfectly successful, without any leak in either the tubes themselves or the stuffing-boxes at the ends of the tubes.

As regarded the proportion of condensing surface used by Mr. Hall, the condensers in the "Wilberforce" had about $14\frac{1}{2}$ square feet of condensing surface per nominal horse power, and the engines worked at about double the nominal power, so that the actual condensing surface was $7\frac{1}{2}$ square feet per indicated horse power, whilst in the "Mooltan" it was only $2\frac{1}{2}$ square feet per indicated horse power. The difference however was explained by reference to the indicator diagrams (Figs. 13 to 15, Plate 35), from which it was seen that in the "Wilberforce" (Fig. 15) a cylinder full of steam at atmospheric pressure was thrown into the condenser at each stroke; whereas in the "Mooltan" (Figs. 13 and 14) the steam was let out into the condenser at only 2 or 3 lbs. above the condenser vacuum, requiring consequently a much smaller proportionate amount of surface for condensation to maintain the same degree of vacuum.

Mr. T. HAWKSLEY could confirm the proportion just mentioned of the condensing surface per indicated horse power in the "Wilberforce", having understood from Mr. Hall that he generally adopted the proportion of not less than 6 square feet of condensing surface per indicated horse power, the steam being at that time exhausted into the condenser usually at about atmospheric pressure.

Mr. F. J. BRAMWELL regretted that the question of nominal and indicated horse power was mixed up in the consideration of the condensers; and thought the comparison should be made upon the basis of the weight of water condensed per square foot of condensing surface per hour, having regard to the vacuum at which it was condensed. A few years ago he had made some experiments on

surface condensation, in conjunction with Mr. Cowper, which were conducted with great care: the steam was passed through a horizontal tube immersed in an open trough of water, and the weight of water condensed was ascertained, with the weight of the water passed through the trough to condense it; the amount of heat put into the condensing water was also observed, and the loss due to radiation was allowed for. It was found that with a stream of water entering the trough at the end at which the condensed steam left the tube, when the steam entering the tube was maintained at exactly atmospheric pressure, $37\frac{1}{2}$ lbs. of steam per hour were condensed and brought down to a temperature of 107° Fahr. by every square foot of external surface of the tube, the stream of condensing water entering the trough at 41° and leaving it at 100° at the end at which the steam entered the tube.

Mr. HUMPHRYS observed that in the condenser described in the paper the condensing water driven in through the inlet pipe at the bottom caused a continual rush of cold water over the surface of the tubes; and as the water became heated it would immediately rise to the top of the condenser and be discharged through the outlet valves. If any increase of temperature were found to take place in either division of the condenser, the regulating outlet valves afforded the means of turning a greater current of the condensing water through that division; and in ordinary working the current of water was equally divided between the two portions of the condenser by the regulating valves. By thus keeping a constant and uniform flow of cold water over the surface of the tubes the proportion of condensing surface was reduced to $2\frac{1}{2}$ square feet per indicated horse power, which he believed was as small a proportion as any surface condensers were working with.

The CHAIRMAN enquired whether the efficiency of the condensation was found to increase very much with the quantity of cold water driven through the condensers.

Mr. HUMPHRYS replied that he had just received the account of an experiment which had now been tried on that point with the condensers of the "Mooltan." In crossing the bay of Biscay the temperature of the sea rose gradually from 58° to 70° Fahr.: and at the higher temperature the vacuum in the condenser of the forward engine was

26 $\frac{3}{4}$ inches of mercury, and in that of the after engine 26 $\frac{1}{2}$ inches. The discharge valves of the condenser of the after engine were then closed, so as to allow the whole of the condensing water driven by the centrifugal pump to pass through the other condenser, and the vacuum in the forward condenser was thereby raised to 27 $\frac{1}{8}$ inches; that is it rose $\frac{3}{8}$ inch when the quantity of water passing through the condenser was doubled. Practically therefore no difference was produced in the condensation by increasing the quantity of condensing water beyond that employed for maintaining the vacuum in ordinary working.

Mr. E. A. COWPER could confirm what had been stated by Mr. Bramwell as to the experiments that they had tried on surface condensation: the experiments being made with the tube placed in an open trough, all the changes that took place could readily be observed. The first change that took place in the appearance of the tube was that it began to look as though it had a bloom on it, a sort of foggy or misty appearance, which was attributed to the air in the water coming in close contact with the tube and remaining there. This was wiped off, but soon returned again, and after a time small bubbles of air began to be formed on the surface of the tube, increasing in size from 1-32nd inch diameter up to as much as about 3-16ths inch, when the bubbles began gradually to leave the tube and float up through the water. But before this took place, one half of the tube surface was enclosed in air, in a sort of air jacket, which effectually kept the water from close contact with that part of the tube. After the air bubbles had been brushed off, they began to collect again, and in a few minutes the same effect was produced; so that in regular working he was satisfied that with horizontal tubes one half of the surface was non-effective when the water was at rest, the non-conducting layer of air keeping the water from the tubes. The horizontal position of tubes in condensers he therefore thought was erroneous in principle, whether the water were outside or inside the tubes. In the experiments the steam was inside and the water outside, whereby there was less obstruction to the air in rising from the horizontal tube than when the water was inside; for it was evident that if the water was inside, unless there was a great rush of water the air would remain in

the tube, and the upper part of the tube might be thoroughly coated with air. He thought it was preferable in practice to put the condenser tubes vertical, with the water inside them; and believed that a strong current of water up through the tubes in the direction in which the air bubbles would naturally rise would be very efficient in brushing them off. It might even be worth while to put a spiral brush inside each of the tubes in the condenser, which would not seriously obstruct the passage of water through the tubes, and might occasionally be moved up and down a few inches in order to remove the air bubbles. It was clear that a large portion of the surface of the tubes was covered with air; and this ought to be borne in mind in constructing any condenser, whether the tubes were vertical or horizontal, or the water inside or outside.

The CHAIRMAN enquired whether the effect of a strong current of water in removing the air bubbles from the surface of the tubes had been ascertained.

Mr. E. A. COWPER replied that he had tried experiments to ascertain the effect of a current, and found that a strong current of water, equal to 10 feet head, running freely, brought the air bubbles off pretty well: 3 feet head of water brushed a few of them off, that is all that were as much as 1-8th inch diameter; but if there was no current, they would increase to the size of 3-16ths inch diameter before quitting the surface of the tube. But he had not been able to get any current strong enough to take the bloom of minute air bubbles off the tube, and considered this could be done only by direct mechanical means. He thought therefore the tubes ought to be vertical, with the water passing up through the inside of them, as the sectional area of passage inside the tubes was less than that outside, so that the velocity of the current of water would be greater over the surface. Moreover in a forest of tubes, as in the condenser shown in the drawings, there was a difficulty in getting any strong current of water into the middle of that forest, unless there were openings or gangways purposely left amongst the tubes for it to pass in. No doubt the condenser described in the paper was a very efficient one; the only question was whether it could not be made still more efficient.

In reference to the durability of the tubes used in the condensers, some of the brazed tubes used by Mr. Hall certainly did split and leak, though many of them answered their purpose very well: but it was undoubtedly a great advantage in the construction of surface condensers at the present time to be able to obtain such sound tubes as the solid-drawn copper tubes now exhibited.

The action of grease in the boilers when surface condensers were used appeared not to have been generally understood: copper boilers were very common just before the introduction of Hall's surface condenser, but as soon as it was applied iron boilers were used, which were found to suffer considerably from little holes being eaten into the plates inside; and it was supposed that small particles of copper from the condenser tubes were carried over into the boiler with the distilled water, and that a sort of galvanic battery was formed which produced the small holes in the boiler plates. He believed however that this was a mistaken idea, and that the effect was not produced by galvanic action, but more probably arose from the grease and tallow used to lubricate the engine becoming decomposed by the constant action of steam or hot water. If any ordinary fat, such as tallow or the common oils having a neutral base, were boiled in water or submitted to the action of steam for a long time, a fat acid was formed; and the fat acids were very actively corrosive, particularly on iron. Hence the grease settling on the sides of the boiler, and becoming an active fat acid, would eat into the iron plates just like sulphuric or any other acid, dissolving the metal chemically; and he believed this was the sole cause of the boilers being damaged when surface condensers were used.

Mr. G. H. BOVILL observed that it was of importance to have some information as to the actual amount of difference in efficiency between vertical and horizontal tubes for condensing. He remembered that some years ago, when experiments were made with Du Tremblay's surface condenser, it was found that there was a great advantage in having horizontal tubes in the condenser; and in the case of several large surface condensers for sugar works, put up by Mr. Pontifex, in which the tubes were horizontal and the condensing

water was supplied in a sort of shower bath on the outside of the tubes, a much better result was obtained with the horizontal tubes.

With reference to the failure of Hall's condenser, he believed a great deal was due, as had been suggested, to the defective make of the brazed tubes. At the time when the experiments described by Mr. Bramwell and Mr. Cowper were made, which were conducted for the purpose of Du Tremblay's condenser, it was considered advisable to test every tube, as it was of great importance to get good sound tubes. Each tube was tested under water with a considerable pressure of air, so that the slightest leakage was detected by the air bubbles rising; and when thus tested the percentage of leaky tubes was very large, although they had appeared perfectly sound under steam proof; therefore, although the tubes in Hall's condensers might have appeared sound, unless they were put to some such severe test they might have failed in working. Moreover in the engines where Hall's condenser was formerly applied the pistons had the old hemp packing, and great quantities of tallow were accordingly used. Now however the surface condensers had certainly a better chance of success than ever previously, and he thought much better results might be expected with the present improved constructions. He enquired how the expansion of the tubes had been found to act upon the joints at the ends of the tubes in the condensers of the "Mooltan."

Mr. HUMPHRYS explained that every tube was perfectly free to expand by means of the stuffing-box at each end; but by screwing down the gland tighter at one end the tube was practically made a fixture at that end, being still free at the other end, and no trouble whatever had been experienced with the joints.

Mr. W. RICHARDSON enquired what means could be employed to prevent the injurious effect of grease upon the boiler plates when a surface condenser was used, from its lodging upon the plates over the fire and allowing them to get hot, and also from its corrosive action upon the plates.

Mr. E. A. COWPER replied that a simple plan for preventing the grease from acting in any way upon the boiler plates was to give it something else to act upon, by placing a lump of chalk or some similar base in the boiler, which neutralised the acid; a solid insoluble

soap was thus formed in the boiler, nearly as hard as chalk, which remained unchanged in the water for any length of time. He had seen large lumps of this neutralised grease taken out from a boiler, which had done no harm to the plates and caused no trouble; they either floated on the surface or went down to the bottom in solid lumps, and no priming was occasioned by their presence in the boiler. In ordinary boilers without surface condensation, the grease was carried away with the water; but with surface condensers returning constantly the same water to the boiler, the strength of the acid grease was continually augmented, and it became necessary to add the neutralising base purposely, to prevent injurious action on the plates, unless there was sufficient impurity in the water that was added to make up for waste.

Surface-evaporative condensers with horizontal tubes and the steam inside the tubes, having water trickling outside to keep them wet, as had been alluded to, had been made by Mr. Perkins with iron tubes $1\frac{1}{4}$ inch diameter, double the diameter of the copper tubes exhibited. In that plan of condenser it was necessary to have the tubes horizontal, because if they were placed vertically it would evidently be very difficult to keep them wet from the top to the bottom, and this indeed could be done only by a perfect shower of water; whereas when they were horizontal they could be kept wet with a very little water. This plan of condenser with horizontal copper tubes had long been used by sugar-boilers for evaporating the saccharine solution. He had put up several surface-evaporative condensers made by Mr. Perkins for steam engines, and they answered admirably.

Mr. T. HAWKSLEY mentioned that Mr. Hall made an excellent glass model of the condenser with glass tubes, in order to observe the difference of action with horizontal and vertical tubes, the steam being inside the tubes in both cases. When the tubes were horizontal, the steam being let in at one end, the other end of the tubes was filled with water; and on the steam being let in, the water was observed to be blown forwards 6 or 8 inches, and afterwards returned again gradually along the tubes, so that they were in fact never clear of water. When the tubes were vertical, and the steam admitted at the

top, they were of course always empty. With the horizontal tubes however the condensed water inside the tubes became very cold and the steam appeared to be rapidly condensed by contact with it; so that there was no observable difference in the time occupied by condensation, whether the tubes were horizontal or vertical.

The CHAIRMAN remarked that there must be an analogy between surface condensers and boilers with horizontal and with vertical tubes; and it was known that in boilers with vertical tubes the production of steam was less rapid, owing to the lodgment of air upon the outside of the tubes. He suggested that it might be practicable to combine the advantages of both forms of condenser by causing the current of condensing water to be driven across the tubes; in which case, so far as lodgment of air on the tubes was concerned, precisely the same cooling effect would be produced as in the horizontal arrangement, while at the same time the tubes would be perfectly drained by their vertical position. In the condenser shown in the drawings the current of water appeared to be an ascending one, parallel with the tubes instead of across them.

Mr. T. HAWKSLEY said the plan of driving the current of condensing water across the tubes had also been tried by Mr. Hall, but no advantage was found to be derived from it.

Mr. J. F. SPENCER remarked that, in reference to the prevention of corrosion in the boilers when surface condensers were used, he had had two or three serious cases of corrosion in boilers, and in each case it had been stopped by the simple plan of making a change in the water supplied to the boilers, which he believed was the best remedy. Whether the corrosion arose from the acid of the grease, or from the presence of copper, or from whatever cause, it might easily be removed by shutting off the auxiliary boiler and supplying a small quantity of salt water, so as to make a complete change in the water during a given period of time. In the steamers of the Canadian line a serious corrosive action had been found to be going on in many parts of the boilers, which was completely stopped by this means, and no such action had taken place since.

Mr. E. A. COWPER had heard of a vessel fitted with surface condensers, which made a few voyages to America and back, and

the boilers were nearly destroyed by the corrosion, having been supplied with distilled water from the first. In a sister vessel however the boilers were filled with salt water in the first instance, and then the supply was kept up with distilled water, and they were not found to corrode.

Mr. J. F. SPENCER said that was the case he had referred to, and both the ships were fitted with surface condensers in the same way: the first ship ran three voyages to America and back before the corrosive action was noticed; but in the second ship the corrosion was checked almost as soon as it had commenced.

Mr. G. H. BOVILL enquired whether the boilers in these American vessels were new boilers, or old boilers to which new surface condensers had been applied. If they were new boilers he could understand that by admitting a certain quantity of salt water to give a kind of encrusted surface to the plates the corrosive action upon them would be prevented.

Mr. J. F. SPENCER replied that the boilers were quite new in both cases. In another vessel that had now been running for about five years, the boiler had been worked with surface condensers from the first, but the water had always been changed from the commencement at regular intervals; in this instance the boiler was still very nearly in its primitive condition, and scarcely deteriorated at all, and the boiler tubes had lasted $4\frac{1}{2}$ years, which was about the usual average.

Mr. HUMPHRYS said that, as to the deterioration of boilers when surface condensers were used, the experience in the "Mooltan" had been most satisfactory; the boilers were as perfect now, after the vessel had run 42,000 miles, as when they were started; there was no appearance whatever of any corrosive action in them, though no precautions whatever had been taken to prevent it. In the case of the "Grappler", he had carefully examined the insides of the boilers after they had been at sea on the coast of Africa for three years, and no corrosion had taken place; and also in the boilers of the "Penelope" there had been no corrosion after six years' work: both these vessels having Hall's condensers. He was at a loss to account for the corrosion stated to have occurred in the other instances that had been mentioned, where surface condensers had been used.

Mr. G. H. BOVILL enquired whether the waste of water from the boilers in the "Mooltan" was made up with salt water or distilled water; and also whether the boiler tubes were made of different metal in these boilers and in those which had suffered from corrosion.

Mr. HUMPHRYS replied that the waste of water in the boilers was made up with distilled water in the "Mooltan", as well as in the other cases that he had named; there were no tubes in the boilers, which were constructed on the plan of a series of alternate flat flues and water spaces, and were entirely of iron.

Mr. J. F. SPENCER said the tubes in the boilers he had spoken of were iron tubes; but the corrosion was not confined to the tubes, but acted equally on the plates of the boilers.

Mr. T. HAWKESLEY remarked that in the land engines to which Mr. Hall applied his surface condensers no corrosive action was observed in the boilers, which were iron boilers of an ordinary kind.

The CHAIRMAN understood superheating of the steam had been adopted in the "Mooltan", and enquired whether the peculiarly successful results of the surface condensers, more especially as regarded the preservation of the boilers, could be ascribed in any way to that circumstance. He asked also what amount of saving was effected by superheating the steam.

Mr. HUMPHRYS replied that the engines of the "Mooltan" were working with superheated steam, but he did not consider that this could bear at all upon the prevention of corrosion in the boilers. The amount of saving effected by the superheating in this case he had not been able to ascertain accurately, having had no means of analysing the results to learn the proportion due to superheating. The readiest method was to take the indicated horse power of the engines as the basis of comparison; and with this standard he was satisfied that a considerable saving of fuel was effected by superheating in comparison with other vessels using ordinary steam, having obtained an economy averaging from 15 to 30 per cent. with superheated steam. Such an amount of saving was of great importance when it was considered that some companies were now paying as much as £800,000 per year for coals. At the time of fitting the "Ceylon" with engines 2½ years ago he put in a superheater made of sheet iron with plates ¼ inch

thick ; and three months ago the plates were found to be nearly cut away with the rush of steam, having been in work $2\frac{1}{4}$ years. The saving effected was so satisfactory, amounting to about 22 per cent., that the iron superheater had now been replaced by one of copper weighing 10 tons.

The CHAIRMAN enquired what amount of superheating was given to the steam.

Mr. HUMPHRYS replied that the steam was heated to about 310° or 320° Fahr., and sometimes as much as 350° , the object being to give about 100° of superheating, though 80° was found sufficient in practice for obtaining good results. He did not think the superheating could be carried to a greater extent without causing trouble with the rubbing surfaces by evaporating the lubricating material.

The CHAIRMAN asked whether the present successful use of the surface condensers could be ascribed to the use of a smaller quantity of grease in the engines than formerly.

Mr. HUMPHRYS thought the success of the surface condensers was mainly due to that cause, as very little grease was used in the engines fitted with the surface condensers. A pipe open to the water space of the boilers was attached to the top of each cylinder, so that if the engine began to "sing out" for want of lubrication a small jet of water was turned on into the cylinder, to prevent its being too dry : there was also the means of supplying oil, but the main resource was water, which satisfactorily answered the purpose.

The CHAIRMAN remarked that all engineers must agree in feeling themselves under an obligation to Mr. Hall who originally proposed the system of surface condensation, though he did not succeed in bringing it fully to maturity ; and they were much indebted to Mr. Humphrys for now bringing forward this interesting and important subject, having succeeded in reviving a valuable invention which had fallen into abeyance for so long a time. It might be remarked in connexion with the surface condenser that the solid-drawn copper tube now exhibited afforded an example of how progress in one manufacture administered facilities to other branches of engineering ; for it was clear that the brazed tube, however it had

succeeded in the condensers described in the paper, was by no means equal to the solid-drawn tube; and undoubtedly the introduction of the latter would be a great advantage in perfecting the system of surface condensation.

He proposed a vote of thanks to Mr. Humphrys for his paper, which was passed.

The following paper was then read :—

ON THE APPLICATION OF THE COPYING PRINCIPLE IN THE MANUFACTURE AND RIFLING OF GUNS.

BY MR. JOHN ANDERSON, OF WOOLWICH.

At the Newcastle Meeting of this Institution in 1858 the writer gave a paper on some applications of the Copying or Transfer principle in the production of wooden articles. The object of the present paper is to give a continuation of the same subject with reference to productions in metal, more especially in connexion with the manufacture of rifled guns or similar structures.

The leading feature in all modern contrivances for producing a definite form of precise dimensions is the introduction of the required form into the apparatus in various ways, by means of sliding rests, rolls, or dies, and under many other modifications; the machinery being arranged generally in such a manner that the required form may be transferred to the article under operation without being dependent upon any particular skill of the attendant workman, beyond that minute acquaintance with the principles of the cutting or working of the metal and the best formation of the cutting instrument or other details, upon which so much depends as regards both quality of produce and cost of manufacture. In looking back to the early days of the turning lathe, before the introduction of the transfer principle in the sliding rest, it is interesting to observe that even then the lathe was a perfect instrument so far as it was a copying machine; those common lathes that were made with a perfectly round spindle neck, if any such existed, would yield a round figure in the article under operation, providing that the cutting instrument was held steadily. And even in a still higher degree was correct workmanship attained in the old-fashioned dead centre lathes; if the centre holes in the article to be turned were formed with moderate care and the article held steadily between the centres, then

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the surface developed by the cutting instrument when firmly held would be as perfect a circle as one described by a pair of compasses.

With such apparatus however the chances of error were numerous, arising principally from the spindle necks not being perfectly round ; for even in the case of modern lathes a perfect spindle neck is more rarely obtained than is generally supposed, as a close examination will show, the polygonal form being much more predominant than the true circle. There are lathes, even among those of the most recent make, which have only to be handled gently to show their condition in this respect. Until recently such approximations to roundness were sufficient ; but the extensive introduction of the Whitworth gauges into workshops has, besides teaching the importance of precise dimensions, made engineers familiar with true circles. Hence there is now a much greater appreciation of positive truth of workmanship, where truth is important ; and in well conducted workshops there is a constant striving after that condition and a gradual closing up of every avenue whereby error can creep in.

Such extreme accuracy is sometimes thought to be more costly than a less careful system ; but the writer has arrived at a contrary opinion, and is convinced from observation in other workshops as well as in that under his own superintendence that while extreme accuracy may be more expensive at the outset, especially from the want of workmen competent to carry it out, yet with a little perseverance the advantage arising from it will be clearly perceived and the apparently inordinate cost will shortly be brought below that of less perfect arrangements. Many articles after being carefully turned and planed have to undergo a long course of filing and scraping before they are brought to the required quality of surface ; whereas if a small fraction of this outlay were spent in making the copy in the lathe spindle or the copy in the plane perfect as patterns, the great expense of subsequent fitting would be avoided. Many examples bearing on this point could be given were it required : an illustration may be named that came under the writer's experience in the manufacture of guns at Woolwich Gun Factory. Certain rings about a foot in diameter had to be fitted on corresponding cylinders, and were required to be perfectly easy to move, yet without

shake, as any looseness in the fit rendered them useless ; they had therefore to fit approximately like the Whitworth gauges. Several good new lathes were tried in vain ; endless scraping and grinding had to be resorted to. Still the writer was convinced that if the source of roundness were positively round, the result ought not to be out of truth. Measures were accordingly adopted to obtain perfection of roundness and steadiness in the lathe, at little more than the cost of fitting one of the rings ; and the subsequent cost of the rings was thereby reduced from the value of nearly three days' work to less than an hour's. The lathe spindle became a true copy, the sliding rest a correct medium of transfer, and the combination of the two yielded the required truth and roundness. A similar case occurred in the manufacture of a number of large fire cocks : the sockets and plugs were carefully turned, but they would not resist the water pressure without a great deal of scraping and grinding, until the lathe spindle was positively brought to perfect roundness, when the turning alone made them fit with scarcely any grinding. The lathe is a copying machine, and just as its bearing surfaces are so is the work produced.

In preparing the successive layers of tubes or cylinders for building up the Armstrong gun, it is absolutely essential that strict attention should be paid to the truth and concentricity of the several parts, in order to obtain a bearing of the whole surface ; more especially as the work approaches completion is it necessary to ensure truth and correct surfaces. With the view therefore of securing these results without being entirely dependent on the men who attend to the turning lathes or even on the accuracy of the lathes themselves when they are old and not very reliable, and with the view also of preventing the quality of the work from degenerating when attention is withdrawn from this part of the manufacture, the writer has adopted the methods about to be described, by which the object is attained with simple arrangements for transferring the original and carefully prepared true roundness to the successive portions of the guns ; and although containing no new contrivance, still a description of the particular arrangements adopted may be interesting.

As before observed, although a perfect circle might be expected to be obtained from a dead centre, the actual result depends on the condition of the centres. The centre point may be polygonal, even though to the eye it appears round; and if the centre hole is carelessly made with a common drill, the chances are many that it is not round. Hence under such circumstances the work turned will not be true, but will be in form some combination of the two surfaces by which it has been produced: but if both these are round, the work turned will be truly round also. The rough cylinders or tubes for the guns as they arrive from the forge are first fitted with temporary centres, and are then turned on a dead centre; after which the temporary centres are removed, the turned part of one end of the tube is pushed into a chuck and the other end is placed in a bearing. The true surface which is obtained from the dead centre becomes the copy and form for the after opening of a portion of the interior by a slide rest; this interior portion then becomes the guide for a half-round boring bit, which again in its turn is the instrument to transfer the copy of the round hole onwards, although in an imperfect manner when strictly examined. A repetition of the process by another opening and a second boring bit still further improves the bore; but even still when carefully measured it is imperfect, although ready for being turned on the outside. Previous however to the turning being performed on the outside of this first or inner tube, a second or outer tube is treated and bored in a similar manner, but still more carefully; and with this outer tube an attempt is made at correct dimensions in the bore. After boring, it passes to a measuring department to have any line of roughness on the surface of the bore removed: the correct dimensions are carefully taken at every twelve inches to three places of decimals by means of a vernier instrument, and all the dimensions are recorded on a slip of paper, together with the respective amounts of contraction to be given. The latter are always represented by a decimal in the third place, amounting to one, two, or three thousandths of an inch; differing according to the part where it is deemed most advantageous to make the first seizure, and gradually diminishing towards the muzzle end in order that there may be freedom for the longitudinal contraction.

It may be useful here to direct the attention of engineers to the use of the vernier for fine measurement. In the Royal Gun Factories it is the familiar instrument for measuring, and now that its value is known it is surprising that it should be so little employed except for mathematical instruments; for by its use the thousandth part of an inch is as easily read off as larger dimensions. Some of the most recent machine tools are graduated only with thick coarse lines, by which it is impossible to set or adjust the machine with any degree of accuracy except by a process of trial and error. If these machines had a vernier, the error could be reduced a hundredfold without the use of a microscope, merely by having the standards of the machine graduated in inches subdivided into 10ths, with a vernier of 99-10ths of an inch (or 9·9 inches length) placed on the horizontal slide which has to be adjusted, the vernier being again subdivided into 100 equal parts, each of which would consequently be 1-1000th of an inch less than the 1-10th inch divisions of the main scale; by this means the dimensions would be read off by eye to 1000ths of an inch, without having to observe divisions finer than 1-10th of an inch.

By means of the vernier the exact dimensions of the bore in the outer tube of the gun are obtained. These dimensions are rarely if ever what they were intended to be, although the true dimensions are aimed at in boring; but any one attempting to make a correct Whitworth gauge even on a small scale will find out how difficult the task is. Even in some such gauges that are made by other makers it is only necessary to try the plug from both sides of the gauge to see at once that the pretension to accuracy is a mere delusion. As it would be very expensive therefore to obtain fixed dimensions in a long tube, and since moreover in a structure to be built up they are not necessary, provided the actual dimensions are correctly known from the vernier, the bored tube is taken as it comes from the boring machine with all its imperfections, often amounting to 5-1000ths of an inch; the precise dimensions, together with the small addition for the contraction to be given, are recorded on a slip of paper; and along with this slip of dimensions a bundle of corresponding steel gauges carefully marked with ink are sent to the

workman who is to turn the outside of the inner tube ready for insertion into the outer tube. The gauges are marked with ink because the dimensions are too minute to be maintained, and the gauges are never used twice without being verified; that is they return again to the measuring department of the works, and are again written upon with ink for the next tube on which they are to be employed.

For turning the tube a lathe with a round spindle is employed, and one end of the tube is pushed upon a projecting plug on the end of the spindle; the plug is the driver, and is made slightly conical so as to adapt itself to any variation of diameter in the bore. Into the other end of the tube a mandril is inserted by pressure, leaving a foot of projection which constitutes the bearing of the tube at that end, the shifting headstock of the lathe being used merely to touch the extremity of the mandril with a flat centre. Thus one end of the tube receives the truth or error of the lathe spindle, and the other end receives the truth or error of the mandril, the middle being a compromise between the two. In cases where the lathe spindle is imperfect or doubtful, a mandril in a bearing is used at both ends of the tube, thus rendering truth independent of the lathe. The mandrils are kept of sizes differing by one thousandth of an inch, and are carefully made in regard to their truth and roundness. The turning of the tube proceeds in the usual manner until the gauges fit at the several points, and after a little experience a good and attentive turner has no difficulty in working to one thousandth of an inch, provided that care has been employed in making the gauges all of one weight, because the fit is entirely a matter of refined touch and any difference in weight misleads the hand. The many inaccuracies in the diameter of the bore of the outer tube arise from the wearing of the cutting instrument and possibly from a difference in the quality of the metal: they may amount to 5-1000ths or even 10-1000ths of an inch or more. Still by careful gauging the precise dimensions are ascertained, and the fit becomes as good as if the inordinate trouble of making the bore perfectly parallel had been gone into.

When the turning of the inner tube is completed, it is taken with the paper slip and the gauges to the measuring department, and is

carefully gauged by the vernier ; and if found correct it passes to the shrinking department, where the outer bored tube having been heated to a dull red heat is shrunk securely upon it. Every part of the outer tube is then under the proper amount of tension, and a misfit never occurs, since any error in turning the inner tube is detected in the measuring department. If a tube is found to have been turned down too small, it is detained until a corresponding outer tube of smaller bore comes forward, to which it is then adjusted.

In preparing the shorter cylinders which form the outer parts of the gun, all preliminary turning is dispensed with: the rough cylinder is at once held firmly by end pressure in a vertical boring machine, and a strong boring bar with a number of cutters is set to work, which quickly finds its way through; this is repeated a second time and a sufficiently good bore is produced. In this bore the truth is dependent on the circularity of the boring bar, which works in a bearing at one end, the other end being fitted and held in the driving spindle of the machine. The bore is never perfect in size, although correct dimensions are aimed at; it may be one hundredth of an inch or more over or under the proper size, and is generally tapered in consequence of the wearing of the cutters. But such errors are not any disadvantage, since all are detected in the measuring; and corresponding gauges with a paper of dimensions are sent to the turning shop. Thus a proper and correct fit is secured without the expense of attaining perfection in the diameter and parallelism of the bore. In this manner the whole structure is under a previously determined amount of tension, and each layer of cylinders is in the condition for performing its full amount of duty in the gun.

On close observation it is found that the grip of every additional cylinder shrunk on affects the interior of the gun in proportion to its diameter and thickness; hence any careful workmanship bestowed upon boring the innermost tube at an early stage would have been thrown away. The formation of the bore therefore now commences, and it should be perfect in the strictest sense of that word; but such accuracy is attained with only variable success even when the most refined appliances are employed. It is not so much that any one bore

cannot be made perfect, but the difficulty is to ensure that the bore shall be continuously right in a succession of guns, at a small cost and without any special attention on the part of the workmen. The assertion that comparatively few holes of any great length are either of the required size or parallel or even round may not meet with general acceptance; but such is the writer's opinion at the present time, and it is founded on the difficulty which he has himself experienced in securing any one of these conditions. Unless true roundness exists in the copy from which the form is derived, there can be no roundness in the work; and unless a standard of the correct size exists in the instrument, there can be no real attainment of correct dimensions with a cutting tool which is constantly wearing. These are self-evident truths; and the nearer the approach to that point where the maximum of truth and parallelism and the minimum of expense may be said to meet together, the more completely is an important desideratum accomplished in the manufacturing economies of the engineering workshop. By extremely slow cutting and by resorting to grinding, approximations can be made to accuracy; but such a system is slow and expensive and incompatible with economical manufacture on a large scale. Hence other means have to be employed, when accuracy is dependent on the tools and the system, rather than upon the workmen who use them.

In the manufacture of guns, more especially of rifled cannon, one great object is to have the bore of definite dimensions, perfectly straight and parallel. The difficulty of accomplishing this depends entirely on what is considered straightness or parallelism, and on the closeness of measurement which may be adopted. With reference to dimensions: if the bore were completed in its boring up to the exact size previous to rifling, it would, from the rubbing of the rifling block and the rusting and cleaning after proof, be considerably over the size when actually finished. Hence it is found necessary to bore only up to within 2-1000ths of an inch of the proper dimensions, and two plug gauges are employed for the purpose, one 2-1000ths of an inch under the proper size and the other exactly the proper size; the first is 12 inches long and must pass through the bore like the plug in the Whitworth gauge, while the other should not enter. In working

so near, there is of course much liability of exceeding the dimensions ; hence the entrance for the final boring tool is made from the muzzle end where an enlargement is of the least consequence. In the preparation of instruments for such precise boring it is found in practice that adjustable cutters are the most economical and convenient, with packings of the finest paper, which may now be obtained less than one thousandth of an inch in thickness. But in every instance these tools wear to some extent before reaching the other end, even if there is nothing left for the last cutter in the series to cut away. The further end of the bore is therefore smaller than the other to an extent which is never less than one thousandth of an inch ; but this difference is not considered sufficient to warrant the risk that would be incurred in proceeding from the other end a second time with a newly adjusted instrument still untried. In dealing with muzzle-loading guns, the difficulty is much increased in comparison with breech-loading, as the latter afford great facility of arrangement ; and it is to breech-loading guns that the present paper chiefly refers.

In order to prepare for the last boring but one, the original bore of the innermost tube becomes the basis to work from, on the same plan as already described with reference to the previous preparation of this tube for building up the gun. It has lost its truth to some extent by the shrinking on of the exterior tubes, but that is recovered by future steps. A true bearing is then turned upon the exterior of the gun at both ends, and it is placed in bearings on a long saddle in a vertical machine. A boring bar with several sets of cutters is used, which works in bearings at both ends of the gun, and has upon it a block that follows the last set of cutting instruments. The bar revolves in fixed bearings, the gun having a slow motion upwards. There is usually about 2-10ths of an inch in the diameter to be cut out by this preliminary operation, and the aim is to continue the bore up to the required size, namely 2-1000ths of an inch below the finished dimension, but this is seldom done ; care is taken however that the bore is not above the size. It might be supposed that the turned bar and bored bearings would give a round hole, but this is not the case unless they are perfectly round themselves ; hence these portions of the machine are looked upon as a foundation of truth,

and are prepared as carefully as if intended for gauges. The boring bars, although made of steel like the gauges, are constantly wearing and require vigilant attention to keep them up to truth. The hole from this boring is generally nearly straight, but never parallel; hence it is difficult to examine it with gauges, although no other mode of measurement is of any value in giving precise information on so delicate a point.

The next and last boring is done with the intention of making the hole parallel, but with no effort at straightness except what is derived from the bore itself as already made. The tool employed is a long broaching bar, shown in Fig. 7, Plate 39, with six cutters AA arranged in two sets of three each, as shown enlarged in Figs. 9 and 10. The first three cutters have all the work to do, the second set on entering being adjusted to the same diameter and intended only to scrape any of the surface that may be left from the first, which is not much, as there is seldom more than one thousandth of an inch altogether to be cut away. Both sets of cutters cut on the side rather than the front. The value of three cutters for steady cutting is well known; but it is also found that such an instrument is very apt to make a bad polygonal bore unless it copies a true circular form from something else. This true circular form, in addition to straightness of bore, is taken from the bore itself as already made. The transfer is effected by means of the bearing surfaces BB on the broaching block, Fig. 9, which are long spiral surfaces made of gun-metal and filling the bore. In the earlier instruments it was found that straight bearing surfaces on the broaching block were liable to allow the roundness of the bore to wander into a polygonal shape; but by twisting the bearing surfaces into a spiral form round the block, as shown at BB in Fig. 9, this liability has been prevented. An ordinary horizontal lathe is the most convenient for this operation, but it is found difficult to keep the bore sufficiently clear from the cuttings; hence the lathes are placed at a considerable inclination, to allow a stream of soapy water to flow through.

The bore is now within one thousandth of an inch of being parallel, but is never positively correct, though considered sufficiently

so in the present stage of the manufacture. All the tool adjustments for these precise dimensions are performed with great strictness by a special department; still with all the care that can be employed it is found extremely difficult to obtain at once the required conditions of correct size and roundness, with a straight and parallel bore. The gun thus bored, when examined and passed by the measuring department, is ready for the operation of rifling. Without this special department for measuring, the quality of the gun would speedily degenerate and tell unfavourably on the smooth cutting of the grooves in the rifling, since the rifling block is entirely dependent on the bore for its parallelism and steadiness.

The foregoing mode of boring applies to guns that are open at the breech; but in the case of muzzle-loading guns that are closed at the breech the approximation to a perfect bore is obtained by boring entirely from the muzzle and employing extreme care in opening with a slide rest; and then by having nicely fitted bearings behind the cutters so as to transfer the truth of the muzzle onwards, which is accomplished to a certain extent successfully, but not so perfectly as by the former arrangements. Much more skill in the workman is required to produce a perfect bore; indeed it is rare to find a bore which may be pronounced nearly perfect in the strict sense of the word; and any want of that high condition tells severely on the future operation of rifling, when the fitting of the rifling block in the bore is dependent on the parallelism of the bore for its steadiness and smoothness of cutting.

The manner of cutting the interior grooves for rifling the gun is independent of the different descriptions of rifling; and in any plan of rifling, with proper arrangements for transfer from copies, the most recondite descriptions of grooves can be formed inside the gun as easily as straight lines on the exterior.

In 1845, some guns being suddenly required to be rifled, an ordinary planing machine was extemporised for the purpose, and the required spiral was cut on the rifling bar, as shown in Figs. 8 and 13, Plate 39, which was left free to revolve in a bearing. The nut for the rifling bar to work through was attached to the muzzle of the

gun; and the machine being set in motion, its reciprocating action effected the cutting of the spiral rifle groove, and an ordinary dividing plate gave the requisite number of grooves. Such a combination possessed all the elements for rifling guns with a simple spiral that was parallel at the sides and on the bottom; but in practice guns have to be rifled with a continually varying twist, with a varying width of groove, with sudden turns, with the shape of one side of the groove continually altering in form, and with many other peculiarities; and hence such simple arrangements will not suffice for their production, and other combinations have to be resorted to.

During the last few years an extraordinary amount of attention has been directed to the subject of rifled guns; and as most of the inventions have been carried out in the Royal Gun Factory, it has been necessary to provide for executing any description of grooving without having recourse to an elaborate copy for each in the immediate instrument, which is expensive and usually involves the loss of considerable time in getting the gun ready for trial. At the same time it may be stated that the simple square bar cut in a spiral or twisted form, as shown in Figs. 8 and 13, Plate 39, when it can be employed, is the most perfect rifling instrument, because there can be no error in using it, which is not the case when the twist of the grooves is dependent on the adjustment of a machine that is ready to perform any description of grooving. In the construction of permanent rifling bars it is now found that a round bar with a spiral groove cut in it answers the purpose almost as well as the square bar cut into a spiral or twisted form, as shown in Figs. 8 and 13, the spiral groove in the round bar and also the spiral twist in the square bar being both cut in an ordinary screw-cutting lathe. Such bars however cannot readily be applied where the spiral is of increasing pitch, where there are sudden curves, where the grooves shunt, or indeed for any groove which is not a true portion of a screw.

In a rifling machine intended for irregular grooving it is necessary that there should be facilities for cutting any form of twisted groove, first as regards the sides of the spiral, and secondly as regards the

bottom of the groove; and the two requirements must be so combined that all the cutting may be done at the same time.

Such a machine is shown in Plates 36, 37, and 38, which represent the rifling machine employed in the Woolwich Gun Factory. Fig. 1, Plate 36, is a general side elevation of the machine, and Fig. 2 a general plan. Figs. 3 and 4, Plate 37, are transverse sections to a larger scale, and Fig. 5 an enlarged side elevation of the traversing saddle which carries the rifling bar. Fig. 6, Plate 38, is a combined diagram illustrating the principal motions, the tangent bar I which gives the twisting motion to the rifling bar being here represented in the vertical plane, in order that it may be seen in combination with the copy bar O which gives the feed motion to the cutter in the rifling head: the lengths are also shortened in some of the dimensions for convenience of illustration, but the side elevation and plan, Figs. 1 and 2, show the correct dimensions and relative positions of the various portions of the machine.

The rifling bar C, Figs. 1 and 6, is round and parallel, one end being held firmly in a bearing D on the traversing saddle E, with a number of collars to take the pull of the cutter; while the other end is free to turn and slide in a stationary bearing F near the muzzle of the gun G. The longitudinal motion of the rifling bar may be given by any of the planing machine motions; that by the screw H, Fig. 2, is preferred on account of the smooth action which it affords. The twisting motion of the rifling bar is derived from the tangent bar I by means of the rack J sliding transversely on the traversing saddle E and gearing into a pinion on the end of the rifling bar C, Figs. 4 and 5. The tangent bar I can be set at any angle by means of the adjusting screw and graduated arc, or can be made of any shape within the limits that the machine is capable of following the quirks of the rifling. Hence to produce any description of twisting in the grooves of the gun it is only necessary to employ a tangent bar of suitable pattern for the purpose, which will be faithfully copied on the interior of the bore by means of the rack J tracing the pattern. In guns where there are several twists or alterations of form in a single groove it is sometimes necessary to have several differently shaped tangent bars piled one on the top of the other, each of which

is used in turn by adjusting the tracing rack J to the bar to be copied ; and in this way any form however recondite can be accomplished as easily as a regular spiral.

In the greater number of rifled guns the depth of the grooves is uniform, but in others it is a varying surface at different positions of the bore ; hence it is necessary to have the cutting instrument arranged so as to vary in depth as it proceeds along the gun. It is also of importance that the cutter should not rub on the gun as it returns, since the rubbing affects the maintenance of a fine cutting edge on the tool, and smoothness of cutting is an essential condition. It is therefore necessary that the cutting tool shall be in a slide rest or holder in the head of the rifling bar, and capable of being drawn out or in transversely as required. For this purpose the rifling bar C is made hollow, and the tool holder in the rifling head K, Fig. 6, is actuated by an inclined slot L in the internal feed rod M, as shown in the enlarged sections of the rifling head, Figs. 14 and 15, Plate 39. By working the feed rod M longitudinally out or in, a radial motion is given to the cutting tool in either direction. The feed rod M projects from the other end of the hollow rifling bar C, and its longitudinal movement is governed by the roller N which traces the copy bar O, Fig. 6 ; the form of the copy bar O is thus transferred by the lever to the feed rod M, and hence any indentations on the bar O are given to the bottom of the groove in the gun. To prevent the cutting edge of the tool from rubbing in its return, an upper rail P is provided, having a trap R and S to open and close at each end in order to allow the tracing roller N to pass. The drawings represent the machine in the forward traverse, in the act of cutting a groove in the gun, the arrows showing the direction of the motion. During this time the roller N is tracing the copy bar O ; but on arriving at the end of the bar the roller lifts open the trap R, as shown dotted in Fig. 6 ; and when it has passed the trap, the latter immediately falls and forms an incline for the roller to run up in its return course backwards and ride upon the upper rail P, thus pushing the feed rod M inwards in the rifling bar C and thereby withdrawing the cutting tool, which remains withdrawn during the

whole of the return traverse of the machine. When the roller N reaches the other end, it finds the trap S open by means of the balance weight; but the roller folds the trap downwards, as shown dotted in Fig. 6, thus forming a bridge to enable it to pass over. The trap is then opened again by the balance weight, and on starting again in the forward motion the roller drops down the incline T at the commencement of the copy bar O, thus drawing out the feed rod M and thereby advancing the cutter into its working position. The incline T gives the form to the entrance of the groove in the gun, and is generally of very definite shape. It will thus be seen that any description of feed motion can be given to the cutting tool; and hence by means of the tangent bar I and the copy bar O any kind of rifling can be accomplished without difficulty. To illustrate the capability of the machinery, a specimen rifled tube has been made (shown in the International Exhibition) with grooves cut in four different ways, one of which is spiral and wavy, undulating on the bottom, and having the width of the groove formed with a progressive irregularity.

For the purpose of advancing the cutter after each traverse so as to obtain the additional depth required in the next cut, the outer end of the feed rod M has a screw and hand wheel U upon it, Fig. 6, Plate 38, by which the cutter is set up to cut deeper in each successive traverse, until the groove is finished to the required depth. The hand wheel also affords the means of taking up the wear of the cutter, so that all the grooves are finished to exactly the same depth. When one groove is completed, the gun is turned forwards through the required arc by means of the ratchet wheel V upon the muzzle, Fig. 3, Plate 37, which serves as a dividing plate, being made with the same number of teeth as there are to be grooves in the bore of the gun.

Experiments have recently been made with another kind of cutting instrument, by which the whole of the grooves are made at one time by means of a circular rifling head carrying as many cutters as there are grooves to be made. A series of these rifling heads are used in succession, following one behind another on the same bar, each one cutting the groove a little deeper than the preceding one, and by

pulling through ten or twelve of them the grooving is effected. This kind of instrument is applicable only to breech-loaders, but so far as economy is concerned it is the most expeditious of all methods. In some of the rifling tools made on the former plan of withdrawing the cutters in returning, eight cutters have been used ; but it is doubtful whether they are more economical than a smaller number, as time is lost in obtaining perfect adjustment with so many cutters working to one thousandth of an inch. Where no variation is required in the depth of the grooves, a rifling head with fixed cutters can be used, as shown in Figs. 11 and 12, Plate 39. The cutters are here fixed in a block rocking upon a centre pin in the rifling head, to allow them to clear in the return traverse, as in a planing machine : they are set up after each traverse by an adjusting screw in the rifling head, advancing the block in which the cutters are fixed. This rifling head is for cutting the grooves in muzzle-loading guns, the cutters being set to cut inwards from the muzzle towards the breech as the rifling head is pushed down the gun, instead of in the contrary direction as in the rifling head previously described and shown in Figs. 14 and 15.

The copying principle is also used in drilling the various holes for the sights and other parts upon the outside of the guns. In a gun which is intended to hit a target at 2000 or 3000 yards distance, the value of the thickness of a line in half the length of the gun is important ; and as all the Armstrong guns are made so that the several parts interchange, absolute precision in the positions of the several holes is essential. Most of the holes have to be drilled on the side of the gun, where the difficulty of entering correctly is greatly increased on account of the surface being oblique to the direction of the holes ; so that the drill requires to be guided very steadily, and the ordinary plan of dividing off the holes and the use of a centre punch are altogether inadmissible. A cast iron saddle is therefore made to fit upon the gun and also upon the trunnions, being cast in halves, so that the whole of that part of the gun in which the holes have to be made is enveloped in it. The saddle is correctly made with copy holes lined with steel, the several holes being of the required

dimensions of the holes to be made in the gun. Cylindrical drills are employed, which fitting the holes in the copy give the utmost accuracy to the sight holes without any effort.

Mr. ANDERSON exhibited a model of the vernier measuring instrument, enlarged 24 times, for the purpose of showing the mode of using the vernier. He explained that in the scale of the instrument itself each inch was subdivided into twentieths, as the subdivisions carried to that extent were found to be of a size convenient in practice for reading quickly by the naked eye. The sliding vernier scale was constructed by marking on it the length of 49 of these twentieths of an inch, and this length was then subdivided into 50 equal parts, so that each subdivision on the vernier was shorter than a subdivision on the main scale by exactly $\frac{1}{50}$ th of $\frac{1}{20}$ th of an inch, that is $\frac{1}{1000}$ th of an inch, whereby the vernier gave the means of measuring to $\frac{1}{1000}$ th of an inch, although the divisions to be examined by the eye were as coarse as $\frac{1}{20}$ th of an inch. The vernier was read by observing which of the subdivision lines on the vernier coincided most accurately with one of the subdivisions on the main scale; and the vernier reading was then added to the reading of the main scale previously read off by eye. Thus supposing the fractional reading on the main scale were $\frac{3}{10}$ ths of an inch and odd, the $\frac{3}{10}$ ths of an inch or $\cdot 3$ inch would easily be read off at once by the naked eye, by seeing that the zero of the vernier scale fell somewhere between the $\cdot 3$ subdivision and the next further subdivision on the main scale. The additional decimal figures to give the exact dimension would then be read also by eye from the vernier in the manner described; and supposing the 42nd subdivision on the vernier were found to be the first that agreed accurately with a subdivision of the main scale, the additional reading would be $\frac{42}{1000}$ ths of an inch or $\cdot 042$ inch, to be added to the previous reading of $\frac{3}{10}$ ths of an inch or $\cdot 3$ inch on the main scale, thus making the correct fractional reading $\cdot 342$ inch, which would be the actual dimension correct to $\frac{1}{1000}$ th of an inch.

The measuring instrument used for making the various gauges employed in the workshops had a magnifying glass mounted on the sliding vernier frame; and the vernier itself, together with the magnifying glass and the back centre or measuring point, was further carried on a second supplementary slide, moved by a fine micrometer screw. In setting the instrument to any required dimension for trying a gauge, the main slide was first set roughly by eye to the proper graduation on the main scale, and clamped in that position by a set screw; and the supplementary vernier slide was then accurately adjusted to the exact dimension by means of the micrometer screw, the vernier scale being read by the magnifying glass.

Mr. E. A. COWPER enquired whether there was any arrangement to allow for the wear of the long brass strips which formed the bearing surface of the broaching block used for the final boring of the guns.

Mr. ANDERSON replied that there was no means of providing for the wear, and the brass bearing strips all became worn, and required fresh adjustment every time the broaching block was used. With straight bearing strips it was found impossible to get a round hole, the bore being always more or less polygonal, whatever amount of care was used or however slowly the boring was done; but by twisting the bearing surfaces into a spiral form round the broaching block the difficulty was much diminished.

Mr. E. A. COWPER observed that he made a boring machine some years ago for the manufacture of the Lancaster guns, and the plan of boring designed by Mr. Lancaster entailed some difficulty in making the boring bar fit well. The gun was first bored cylindrical; then it had to be bored oval, with the oval twisted. A hollow boring bar was used, revolving concentrically in the gun, and carrying eccentrically within it a solid bar, which carried the cutter and revolved in the opposite direction to the hollow bar, forming an epicycloid movement. The tool projected, then retired, then projected again, and then retired, the double epicycloid forming an oval in one complete revolution. In this arrangement the boring bar had consequently a considerable amount of rubbing in the gun: and the only plan of getting a guide was to make the end of the boring bar fit the cylindrical bore of the gun, and then to thrust it down to the breech of

the gun at the commencement, and bore outwards towards the muzzle, so as to preserve the cylindrical bore as the guide to the last. The whole operation of making the oval bore had thus to be performed with one guiding surface; and it was therefore a point of great importance to get this guiding surface to fit well without any variation from wear throughout the entire length of the bore. He had accordingly turned a broad groove with parallel sides round the head of the boring bar, immediately in front of the cutter, and the bottom of the groove was made slightly inclined or conical. A corresponding brass ring cut into three segments was fitted into the groove, not quite filling the width of the groove; the outer surface of the ring formed the guiding surface, while the inner surface was bored slightly conical to the same inclination as the bottom of the groove. To each segment of the ring was attached a longitudinal wrought iron rod lying in a groove on the outside of the boring bar; then by drawing the three rods forwards by screws, the segments of the ring were drawn up the incline forming the bottom of the groove and were by that means expanded outwards in the gun, thus slightly increasing the diameter of the guiding surface and making up for any amount of wear of its rubbing surface. In this case there was a great deal more wear of the guiding ring than in boring ordinary guns, because the boring bar had a continuous rotary motion for a length of time, the whole of the boring having to be done throughout from end to end of the gun at one operation and by one cutter.

The CHAIRMAN enquired what method was employed for making the lathe spindles perfectly true and round, as had been referred to in the paper.

Mr. ANDERSON replied that the required truth and roundness were obtained only by the usual method of grinding the lathe spindles with an independent grinder running at a high velocity, the lathe spindle revolving slowly in the opposite direction on fine centres. It was a very tedious business to get the spindles true; but when they were once made true, all the work done in the lathe was true also.

Mr. J. FLETCHER had had an opportunity of seeing over the Woolwich Gun Factory, and had been much struck with the great accuracy arrived at in the work performed there. Perfect truth was

almost impossible to be attained, and he had himself experienced the difficulties described in the paper from the wear of tools during the execution of a piece of work, particularly when the work was of considerable length, as in cutting a groove or a screw thread for a length of 30 feet; there was then a perceptible difference in the depth of the cut at the two ends, nor was perfect uniformity obtained by setting up the tool through the amount of wear and starting again from the opposite end to work backwards. The accuracy of the work was moreover affected to an appreciable extent by differences of temperature producing expansion and contraction: and he had noticed this effect in cutting a long screw, which altered in length in consequence of being heated by the cutting tool; and unless it were allowed to cool before finishing, it would when cold be perceptibly different in pitch from the regulator. He had also observed the same effect in a set of three surface plates 8 feet long, which would probably coincide perfectly in the morning, but in the middle of the day the thickness of a thin piece of paper might be got between them, and at other times in the day they would vary still more. It was not possible to ensure having them always in the same position, and at exactly the same temperature, or of exactly the same quality of metal; and hence the difficulty of carrying accuracy in engineering work beyond certain practical limits. He enquired whether in boring the guns to so great a nicety as had been described the outside of the complete gun was turned before the boring was done: because if any piece of metal were bored out first, and then had the outside skin turned off, a perceptible change would be produced in the dimensions of the bore previously made, and it would be impossible to attain accuracy in that way.

Mr. ANDERSON replied that the gun was turned outside with a near approach to the final accuracy, before the boring was done.

Mr. G. H. BOVILL asked what effect the firing of the gun had upon the accuracy of the bore, and whether the bore was accurately gauged before and after the firing, in order to ascertain what variation took place in the dimension after several charges had been fired, in consequence of the friction of the shot and the expansion of the metal from the heat and strain.

The CHAIRMAN said there must be a certain amount of stretch in the gun under the severe strain ; but it was very minute, and he believed not sufficient to affect the practice with the gun. The finishing process of the boring was deferred till after the proving, and the bore was then made as true as possible in roundness and straightness.

Mr. E. A. COWPER observed that the same plan was carried out with good fowling-pieces, which were always proved before they were finished in the bore.

Mr. W. RICHARDSON had been surprised to see the perfection and accuracy of workmanship attained in the Woolwich Gun Factory, and believed he had never seen the same degree of accuracy in any other works. It would be a great advantage if the engineering workshops throughout the country would endeavour to approach to the same amount of perfection, by employing a better class of machinery and tools, which would produce an important advance in mechanical engineering.

The CHAIRMAN moved a vote of thanks to Mr. Anderson for his paper, which was passed ; and observed that the members would have an opportunity of visiting the works at Woolwich and seeing the whole of the processes described in the paper in the manufacture and rifling of the guns ; and also of visiting the Small Arms Factory at Enfield, where the same principles had been carried out by Mr. Anderson, and the same accuracy of workmanship attained.

The Meeting was then adjourned to the following day. In the afternoon the Members visited the new Main Drainage Works and Sewage Pumping Engines in process of execution at Greenwich. Some of the principal engineering establishments in London were also opened to the inspection of the Members.

The ADJOURNED MEETING of the Members was held in the Lecture Theatre of the Royal Institution, Albemarle Street, London, on Wednesday, 2nd July, 1862; THOMAS HAWKSLEY, Esq., in the Chair.

The following paper was read :—

ON THE RELATIONS OF POWER AND EFFECT IN CORNISH PUMPING ENGINES OVER LONG PERIODS OF WORKING.

BY MR. CHARLES GREAVES, OF BOW.

In investigating the working of steam engines with a view to determine with exactness the quantities of fuel and water consumed in producing a measurable amount of mechanical effect, the author has been led to maintain registers of work comparable with the expenditure of materials used, which he thinks may be of service to engineers; partly because they have been carried on through long periods of working and therefore become data of commercial experience, and partly because the facilities for securing accuracy lay in his own hands, as well as means for carrying out some of the measurements on principles not generally adopted.

The engines which are principally the subject of this investigation are of the description commonly known as "Cornish": that is to say single-acting high-pressure expansive condensing engines, working single-acting pumps through the medium of a beam, as shown in Figs. 1 and 2, Plates 40 and 41, which are longitudinal and transverse sections of one of the Cornish pumping engines at the East London Water Works, the steam cylinder A being 100 inches diameter in this engine. The pumps B are all plunger pumps, and the plungers are loaded with iron weights sufficient to counterpoise the pressure of a hydrostatic column which is the measure of the pressure created in the central station to put in action the supply of water to the eastern part of London. The loaded plunger is lifted by the action of the steam in the cylinder A, and is allowed to descend by gravity at a speed depending on the quantity of engine power in action and the rate at which the water is being drawn away. The chamber of the pump becomes filled when the plunger is raised, and the act of inhaling the full charge through the suction valve C is a portion of the work

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which the steam has to perform, and a portion also much subject to variation.

The working of the Cornish engines at the East London Water Works is as follows. The steam is raised in cylindrical single-flued boilers with internal fires to a pressure of 30 to 35 lbs. per square inch above the atmosphere: the boilers are of ample dimensions, and not less than three are at work for each engine; they have large steam chests attached and are all covered up with great care. The engines are worked at all speeds which may be practically included between 4 strokes and 10 strokes per minute. The cylinders are all cased in steam jackets and these again are enclosed in an outer case filled to a thickness of not less than 12 inches with very fine ashes. The cylinder covers have no steam jackets but are well covered in various ways, as are also the steam pipes and upper nozzles or valve boxes. The steam valves are in all cases double-beat gun-metal valves, and in as good order as close care and attention can maintain them. The boilers being filled with steam at 30 to 35 lbs. pressure per square inch, the same pressure fills the steam chest and steam pipes up to the steam valve. The supply for the steam case of the cylinder is taken from the same boilers, and no difficulty exists in maintaining the full heat of the boiler in the steam case, amounting to 282° Fahr. with steam at 35 lbs. per square inch above the atmosphere. The condensed water from the steam case returns by gravitation to one of the working boilers, the cylinders being purposely set at such a level relatively to the boilers as to allow of this continued circulation by mere gravitation, which is not interfered with by the working of the engine, continuing to act during the intervals of work or as long as steam remains in the boiler.

The speed of the engine is regulated by an adjustable cataract: the exhaust valve first and then the steam valve are thrown open by treadle weights, as soon as the catches are detached by the cataract. The valves are closed by tappets on a plug rod D, Fig. 1, Plate 40, first the steam valve E and then the exhaust valve F, the former at a period of the stroke varying in practice between one third and one fifth from the commencement, and the latter at the end of the stroke.

In engines worked on this principle, as also in all reciprocating engines pumping without cranks, there is nothing to limit the strokes of the engine to any exact length. It is necessary therefore that bumpers or catch pieces be provided to restrain the engine at both ends from an undue length of stroke; and thick plates of india-rubber under hard wood blocks are now used for this purpose in place of the spring beams formerly employed. An engine thus arranged, working alone, lifting water from one fixed level to another, would work continuously with one length of stroke and one speed, at whatever it might be set: but in waterworks with direct delivery, that is not pumping into a stand-pipe of constant height of column, but where the levels of the reservoirs vary continually and the velocity of the delivery into the main pipes is subject to continual fluctuation, it is found that a variation to the extent of some inches in the length of stroke results throughout the day; and the engines lengthen and shorten their strokes in obedience to the variable resisting pressure of the column of water. The variable resistance to the loaded plunger in the outdoor stroke causes the piston to stop at a variable distance from the top of the cylinder, a reduction in the resistance causing a greater velocity and a corresponding greater length of outdoor stroke, before the motion is completely arrested by the effect of closing the equilibrium valve. An empirical dimension for length of stroke has consequently to be determined by observation as an average. Each stroke of these engines is an operation complete in itself, including within itself all the changes from rest to rest; and there is no momentum carried on and no arrears of force subsequently supplied.

The stroke of the engine raising the load, technically called the "indoor" stroke, is performed in these engines at the mean velocity of from 500 to 600 feet per minute. When the steam is cut off at 1-4th of the stroke, a 10 feet stroke is frequently performed in 1 second, and 11 feet stroke constantly in $1\frac{1}{4}$ second; and when cut off at 1-3rd, the 10 feet stroke requires about $1\frac{1}{2}$ second. This speed in pumping is almost peculiar to waterworks engines; for in mining engines the same length of stroke generally requires more than 2 or $2\frac{1}{2}$ seconds. Much depends on this velocity. The chamber of the pump having to be filled during the indoor stroke, the dimensions of

the suction valves C, Fig. 2, Plate 41, must be such that the least loss of power may be suffered in drawing the water in; and the adoption of double suction valves has proved very beneficial in economising power. Moreover as it is absolutely necessary for the good working of the engine that the suction valves should be shut quite as soon as the engine concludes the indoor stroke, the lift and loading of the valves are matters requiring considerable attention.

For the purpose of obtaining a high duty, the author's experience would lead him not to put a greater total load on the piston than about 16 lbs. per square inch, including the friction of the engine; this total load being the total pressure on the piston measured by an indicator and averaged over the whole length of the stroke. Now in engines worked in the manner above described at an average speed of about 7 strokes per minute there is no difficulty in maintaining a vacuum in the condenser within $1\frac{3}{4}$ inches of mercury of the atmosphere at the time. Observations on this point have been made for years, from which is deduced an average of 1.66 inch below the atmospheric barometer at the time. Hence the average vacuum maintained in the condenser may safely be taken at 28 inches of mercury, or 13.75 lbs. per square inch. This in action throughout the stroke leaves only the remainder 2.25 lbs. per square inch to be made up by the pressure of the steam, in order to balance the total load of 16 lbs. per square inch on the piston; and therefore a somewhat greater pressure of steam than 2.25 lbs. per square inch above the atmosphere, kept on the piston throughout the whole stroke, would produce motion. If however steam of a much higher pressure be admitted, the motive force will be greater than the load, and it will be necessary to stop the admission of the steam at some point before the end of the stroke, leaving the steam to expand through the remainder of the stroke, in order that the total power may not be in excess of the load to a greater extent than is necessary to produce the required speed of motion.

The accompanying indicator diagrams, Fig. 3, Plate 42, are all taken from one of the engines at the East London Water Works, with five different degrees of cut off, at $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, and $\frac{1}{6}$ of the stroke, but with the same effective load; the effective load being the load to be

lifted, exclusive of the friction of the engine, measured by a pressure gauge in the pump and reduced to the area of the piston. The diameter of the cylinder was 72 inches, and the actual length of stroke 9 feet 7½ inches. The diagrams were drawn successively after working half an hour at each of the different proportions of cut off. They show how as the higher pressure of steam was admitted the earlier cut off was necessary; and how nearly the total power exhibited in the stroke under the different conditions remains uniform, the mean pressure being equal in each case to 15 lbs. per square inch on the piston throughout the stroke, which is therefore the total load on the engine as measured by the indicator on the cylinder, including the friction of the engine. It must however be borne in mind that with the steam cut off at 1-6th and the proportionately higher initial pressure of steam the stroke was made much quicker than with the steam cut off at half stroke, being performed probably at a greater average velocity than 600 feet per minute. The admission indeed of steam at such a high pressure by a double-beat valve approximates very much to a blow on the piston, and must be met by great strength of the moving parts. Figs. 4 to 8, Plates 43 and 44, show the same indicator diagrams drawn out separately; and Figs. 10 to 12, Plate 45, are indicator diagrams from three other engines at the East London Water Works. Fig. 10 is the indicator diagram from the 80 inch cylinder, giving a total load on the piston equal to 14·33 lbs. per square inch, the actual length of stroke being 9 feet 9 inches, and the steam cut off at 1-3rd stroke. Fig. 11 is from the 90 inch cylinder, the total load on the piston being equal to 15·58 lbs. per square inch; the actual length of stroke was 10 feet 7 inches, and the steam was cut off at 1-4th stroke. Fig. 12 is the indicator diagram from the 100 inch cylinder, giving a total load on the piston equal to 16·58 lbs. per square inch, the actual length of stroke being 11 feet, and the steam cut off at 1-4th stroke.

In order to determine with precision the exact point at which the steam valve is closed, an arm was fixed on the valve spindle, having its outer end connected to the rod of an ordinary indicator: then the barrel of the indicator being put in motion in the usual manner, a figure is drawn as the result of the two motions which portrays the

exact rise and fall of the valve on the base line of the stroke. Fig. 9, Plate 44, is a diagram of the lift of the steam valve traced in this way by the valve itself, showing the actual point of cut off in the 72 inch cylinder, corresponding with the five preceding indicator diagrams from the same cylinder. The steam valve is 16 inches diameter, double-beat, and the vertical scale of the diagram is full size, giving the actual lift of the valve. This diagram shows that with the steam cut off at half stroke the lift of the valve is 1.88 inch; at 1-3rd stroke, 1.80 inch; at 1-4th stroke, 1.74 inch; at 1-5th stroke, 1.69 inch; and when the steam is cut off at 1-6th stroke, the lift of the valve is 1.53 inch. The author strongly recommends the use of this contemporary valve diagram to prove the real point of cut off, both as definite evidence particularly applicable to the movement of the valves, and as being easy and convenient of management.

In ordinary registers of steam engine performance it is thought sufficient to give a comparison of the amount of work done, in weight of water lifted to the known height, with the weight of fuel necessary to carry the engine through that amount of work. The registers of duty so long and so ably maintained in Cornwall are based on this comparison; and the ordinary expression of pounds of fuel burnt per horse power per hour, as universally employed elsewhere, is only a different form of the same expression. There is however a defect in the limited information thus given, since it includes in one statement the whole efficiency of the pump, the engine, and the boiler. These registers are indeed invaluable; but if an additional register of the quantity of water ordinarily used as steam can be added, it becomes possible to discriminate between the efficiency of the boiler and the engine, and to investigate the economy of the engine itself without the complication and variations arising from different constructions of boilers, size of fire, quality of coal, and ability of the stoker. The same measurement of the water boiled off is no less a most sure comparative test of the good qualities of the boilers and the fuel; but the investigation of that subject does not come within the purpose of the present paper. The object of the author is to show the quantity of water used as steam in performing the work, with the proportion

which the work actually done bears to the theoretical power of the steam, as deduced in both cases from the final degree of rarefaction of the steam at the conclusion of the stroke.

The true measurement of efficiency in a steam engine is the quantity of feed water used, as has been well shown by De Pambour : and the author having endeavoured to carry out the same plan of measurement can testify most thoroughly to the very exact knowledge of the condition of an engine that is obtained by making the water evaporated per stroke one of the elements of continual registry in the log book or journal of work. The following Table I gives the total

TABLE I.

Consumption of Feed Water per stroke.

	Half year ending	Total No. of Strokes.	Feed Water evaporated.		
			Total.	Per Stroke.	Average.
72 inch cylinder	June 1858	686172	445542	0.649	Average 0.615 gal. or 6.15 lbs. per stroke.
	Dec. "	923490	598075	0.647	
	June 1859	662136	390287	0.589	
	Dec. "	1144711	676990	0.591	
	June 1860	1024225	609630	0.595	
	Dec. "	1025356	639250	0.623	
80 inch cylinder	June 1860	901510	679900	0.754	Average 0.761 gal. or 7.61 lbs. per stroke.
	Dec. "	829444	642350	0.774	
	June 1861	510443	393430	0.777	
	Dec. "	740073	554170	0.748	
90 inch cylinder	Dec. 1857	1506952	1484123	0.984	Average 0.997 gal. or 9.97 lbs. per stroke.
	June 1858	1515208	1459477	0.963	
	Dec. "	881126	903950	1.025	
	June 1859	1359688	1328660	0.977	
	Dec. "	1107643	1092930	0.986	
	June 1860	753049	750650	0.996	
	Dec. "	849576	895150	1.053	
	June 1861	659574	690400	1.046	
100 inch cylinder	Dec. 1858	1541134	2246216	1.457	Average 1.453 gal. or 14.53 lbs. per stroke.
	June 1859	963525	1440918	1.495	
	Dec. "	1070430	1558426	1.456	
	June 1860	1334070	1880850	1.409	
	Dec. "	1346310	1903550	1.414	
	June 1861	1476320	2151945	1.457	
	Dec. "	1564425	2323700	1.485	

quantity of feed water evaporated and the total number of strokes made in successive half years, with the resulting average consumption of feed water per stroke; and these figures being the results of actual experience are not specially experimental or exceptional. The continuous measurement of the feed water has been secured by passing the feed for each range of boilers through one of Kennedy's piston water meters. These meters have been specially tested for the purpose and are periodically examined, cleaned, tested, and re-erected or exchanged according to need. When used with due care the author considers them to be perfectly trustworthy at a cost not deserving to be mentioned in comparison with the value of the reliable evidence they afford.

In order that the total load as measured by the indicator may be compared with the quantity of feed water measured in actual consumption in the boiler, it is necessary to ascertain the actual final degree of expansion of the steam at the end of the indoor stroke, and also the theoretical degree of expansion at which the engine, with a perfect vacuum, and apart from loss and friction, would have completed the stroke. The actual final degree of expansion of the steam at the end of the indoor stroke, from its original state of water, is obtained by dividing the capacity of the cylinder with the working length of stroke by the quantity of feed water evaporated per stroke. The following Table II gives the dimensions of the several cylinders and the final degree of expansion obtained in this way, the consumption of feed water being taken from the preceding table.

TABLE II.
Actual Final Expansion of Steam from water.

Diameter of Cylinder.	Area of Piston.	Length of Stroke.	Capacity of Stroke.	Feed Water evaporated per stroke.		Actual Final Expansion.
				Gal.	Cub. Ft.	
72	28·27	9·62	271·95	0·615	0·0987	2755
80	34·91	9·75	340·37	0·761	0·1222	2781
90	44·18	10·58	467·42	0·997	0·1600	2921
100	54·54	11·00	599·94	1·453	0·2332	2573

The highest degree of actual expansion from water that the author has ever observed has been 3000 times with a total load on the piston not exceeding $15\frac{1}{2}$ lbs. per square inch, and 3134 times with a total load of 15 lbs., the steam being cut off at 1-4th stroke in both cases.

The theoretical degree of expansion at which the steam would have arrived at the end of the indoor stroke, in a perfect engine without loss or friction and with a perfect vacuum, is found by obtaining from the indicator diagram the mean pressure throughout the stroke, which is the total load on the piston; and the simple expansion from water or the relative volume of the steam at this mean pressure, that is the number of cubic feet of steam at that pressure produced from one cubic foot of water, is taken from a table of steam pressures. Then the product of this relative volume multiplied by $(1 + \text{hyp log } n)$, the ordinary formula for calculating the result of expansion, will give the theoretical final volume of the steam at the end of the stroke, n being the number of times the steam is expanded in the cylinder. In this way the theoretical final expansion of the steam is found for any total load and any degree of cut off.

In the 72 inch cylinder the total load on the piston is equal to 15 lbs. per square inch, as obtained from the indicator diagram, Fig. 6, Plate 43; and steam of a total pressure of 15 lbs. per square inch is enlarged in volume from water 1670 times. The steam is cut off at 1-4th stroke, and is consequently expanded 4 times in the cylinder; and $1 + \text{hyp log } 4 = 2.386$. Hence the product 1670×2.386 gives 3985 as the theoretical final expansion of the steam at the end of the indoor stroke. The actual final expansion is seen from Table II to be 2755, showing the imperfection of the working result to be 31 per cent.

In the 80 inch cylinder the total load on the piston is equal to 14.38 lbs. per square inch, as obtained from the indicator diagram, Fig. 10, Plate 45; and steam of that total pressure is enlarged in volume 1733 times from water. The steam being cut off at 1-3rd stroke, $1 + \text{hyp log } 3 = 2.099$. Hence the theoretical final expansion of the steam would be $1733 \times 2.099 = 3638$; while the actual final expansion in Table II is 2781, or 24 per cent. less.

In the 90 inch cylinder the total load on the piston is equal to 15.58 lbs. per square inch, as obtained from the indicator diagram, Fig. 11, Plate 45; and the corresponding volume of the steam is 1612. The steam is cut off at 1-4th stroke, and therefore $1 + \text{hyp log } 4 = 2.386$, which multiplied by 1612 gives 3846 as the theoretical final expansion of the steam. The actual final expansion in Table II is 2921, or 25 per cent. less.

In the 100 inch cylinder the total load on the piston being equal to 16.58 lbs. per square inch, as obtained from the indicator diagram, Fig. 12, Plate 45, the corresponding volume of the steam is 1529; and the steam being cut off at 1-4th stroke as before, 1529×2.386 gives 3648 for the theoretical final expansion of the steam. Table II shows that the actual final expansion is 2573, or 29 per cent. less.

These results are given in a tabular form in Table III:—

TABLE III.

Difference of Theoretical and Actual Final Expansion of Steam.

Diameter of Cylinder.	Point of Cut off.	Total Load on piston.	Final Expansion of Steam.		Difference per cent.
			Theoretical.	Actual.	
Inches.		Lbs. per sq. inch.			
72	1-4th	15.00	3985	2755	31
80	1-3rd	14.38	3638	2781	24
90	1-4th	15.58	3846	2921	25
100	1-4th	16.58	3648	2573	29

Hence in the 100 inch cylinder, the theoretical final expansion of the steam being 3648 times from water, and the capacity of the cylinder for the stroke of 11 feet being 599.94 cubic feet, as given in Table II, and the weight of one cubic foot of water being 62.3 lbs., the theoretical quantity of feed water necessary to expand into this capacity would be $599.94 \times 62.3 \div 3648$ or 10.24 lbs.: and the author therefore concludes that, with the steam cut off at 1-4th stroke and under a total load of 16.58 lbs. per square inch on the piston, the stroke of 11 feet could not be made with less than 10.24 lbs. of feed water under any theoretical conditions whatever; that is even with a perfect vacuum, and with no loss or friction.

The actual consumption of 14·53 lbs. of feed water per stroke in the 100 inch cylinder, as given in Table I, is equivalent to 20·09 lbs. per *indicated* horse power per hour, that is under the total load of 16·58 lbs. per square inch on the piston; and the average load as measured by a pressure gauge *on the main* leading from the pump being 12·81 lbs. per square inch reduced to the area of the piston, the actual consumption of feed water per horse power per hour measured *in the main* is 20·09 lbs. multiplied by the ratio of 16·58 lbs. to 12·81 lbs., amounting therefore to 26 lbs. of feed water per horse power per hour. If this were evaporated at a rate of 8 lbs. of water per lb. of fuel, the consumption of fuel would be 3·25 lbs. per horse power per hour. Therefore the minimum consumption of fuel in a theoretically perfect engine with the steam cut off at 1-4th stroke would be 3·25 lbs. reduced in the ratio of 14·53 to 10·24, amounting therefore to 2·29 lbs. of fuel per horse power per hour measured in the main.

The standard quantity of feed water required to produce a stroke of known effect having been obtained from the average of so long a period of working, it must be remembered that there are probably several causes by which the consumption of feed water per stroke, as stated in the preceding Table I, may have been accidentally increased. The inaccuracy that might arise from blowing out the boilers while in work has been entirely avoided; but there is a constant liability to loss from possible unknown leaks from safety valves and gauge cocks. The chance of spare boilers put on short of water or put off with excess may be balanced by a contrary proceeding. Extra steam is used in starting, which must tell up with the engine working only 12 hours out of the 24.

The causes by which to explain the difference between the actual power obtained from the steam and the theoretical full power are, the friction of the engine: the possible leakage of the piston, of the steam valve while the piston is in partial vacuum during the outdoor stroke, and of the equilibrium valve while the steam is on the piston during the indoor stroke: and the imperfection of vacuum in the condenser, since it is not to be supposed that an air pump is all the year round

in a condition to work at all hours within 1·66 inches of mercury of the atmosphere. Then the cooling of the piston rod during the exposure of every stroke, the condensation of steam on the cylinder cover which has no steam jacket, and the condensation, if any, of steam on the sides of the cylinder itself, which would be evaporated again and pass away through the exhaust valve into the condenser, are evident sources of loss, continually operating. These it is the duty of the engineer to use every means of diminishing, in pursuit of that theoretical economy which would result in still further reducing the difference that yet remains between the power expended and the useful effect produced: and an important step towards the attainment of this object will be to ascertain an experimental value of the loss arising from each source.

Mr. GREAVES remarked that his particular object in the paper just read was to show that there was a definite ultimate maximum of result to be developed from a given quantity of water: and he considered it was important that this should be clearly recognised, because the question of the practical efficiency of an engine seemed to be generally treated as though the effective work that could be obtained were an indefinite result by reason of deducting an indefinite loss in friction &c. from an indefinite theoretical maximum of power. But he considered the theoretical maximum of power was a definite quantity, and the effective work that could be obtained from it was indefinite only as far as the losses from friction and other causes were indefinite. The calculations given in the paper of the useful effect of the engines at the East London Water Works were based on a comparison of the theoretical and actual volumes of the steam at the end of the indoor stroke, each volume being estimated from the quantity of feed water consumed per stroke, which was capable of very exact measurement by extending the observations over long periods of working.

There was one point to which no reference had been made in the paper: the clearance space in the top of the steam cylinder and in the steam passages, which had not been taken into account in the calculations. The total clearance space in the 100 inch cylinder, including that in the top of the cylinder and in the steam way as far as the steam valve, was not less than 20 cubic feet or $3\frac{1}{2}$ per cent. addition to the capacity of the stroke, in the 90 inch cylinder 15 cubic feet or $3\frac{1}{2}$ per cent. addition, in the 80 inch cylinder 12 cubic feet or $3\frac{1}{2}$ per cent. addition, and in the 72 inch cylinder 10 cubic feet or $3\frac{1}{2}$ per cent. addition to the capacity of the stroke. If the clearance were included in the total capacity of the cylinders, the degree of actual rarefaction of the steam as deduced from that capacity would appear greater; but the ratios of actual rarefaction given in the paper were in all cases within about $3\frac{1}{2}$ per cent. of the practical result. And as regarded the theoretical rarefaction, deduced from the number of times the steam was expanded in the cylinder, the addition of the clearance space would cause the cut off to take place virtually at a later point of the stroke, and would diminish the theoretical rarefaction. The ultimate result of both effects in the case of the 72 inch cylinder would be to make the actual expansion only 25 per cent. less than the theoretical, instead of 31 per cent. less as given in the paper, being 6 per cent. reduction, or 6 per cent. addition to the efficiency of the engine: and in the other engines the difference between the actual and theoretical expansion would be similarly reduced by about 6 per cent., the ultimate differences being only 18 per cent. in the 80 inch cylinder, 19 per cent. in the 90 inch cylinder, and 24 per cent. in the 100 inch cylinder, instead of 24, 25, and 29 per cent. respectively as given in the paper. The actual amount of steam wasted in consequence of the clearance was only the quantity required to raise the pressure in the clearance space up to the pressure at the point of cut off, this space being already filled at the commencement of the indoor stroke by exhaust steam compressed to the pressure that exactly balanced the weight of the loaded plunger. The clearance space had also the effect of raising the line of pressure in the indicator diagrams, particularly towards the end of the stroke.

The indicator diagrams accompanying the paper were not selected as representing any particularly high amount of duty or very excellent form; but rather as showing by the five diagrams from the 72 inch cylinder the different form of diagram that was drawn with the load remaining the same but the expansion varied, as shown in the combined diagram, Fig. 3, Plate 42.

Mr. W. POLE enquired at what point of the stroke the steam was cut off in the ordinary practical working of the engine from which the diagrams had been taken. Experimentally an engine might be treated in various ways, but it was desirable to know what was considered the most advisable point for cutting off the steam in regular practice. One of the engines referred to at the East London Water Works had been very thoroughly experimented upon and described by Mr. Wicksteed and partially also by himself, and in that case the steam was cut off only at 1-3rd stroke.

Mr. GREAVES replied that the five comparative diagrams with different degrees of expansion were taken from the 72 inch cylinder; but the engine upon which a great many experiments had been made by Mr. Wicksteed was the 80 inch cylinder, the first engine brought up from Cornwall and the first Cornish engine used for water works at all. In that engine the steam had never been cut off earlier than 1-3rd stroke, for the engine was bought ready built and had small steam passages, so that it was not easy to get a higher degree of expansion in it: but in the 100 inch cylinder that had since been put up by himself, and in the 90 inch cylinder erected by Mr. Wicksteed in 1847, the steam was cut off uniformly at 1-4th stroke, as shown in the indicator diagrams from those cylinders, Figs. 11 and 12, Plate 45. The 72 inch cylinder put up in 1856 was usually worked also at a cut off of 1-4th stroke, and had been worked occasionally at 1-5th and 1-6th: but he did not think extreme degrees of expansion were desirable, as the higher initial pressure of steam then required produced rather a sudden blow on the piston and caused a great strain on the machinery. He had found that a cut off at 1-4th stroke was a very convenient degree of expansion for regular working in such engines.

Mr. W. POLE concurred in considering it very difficult in practice to work with a high degree of expansion in a single cylinder engine, and believed it was generally found best on that account to limit the expansion to a small amount. Theoretically indeed the greater the expansion the more work was got out of the steam, and therefore to get a high duty a high expansion was required: in Cornwall the expansion had been carried as high as ten times in a single cylinder in engines in good condition, and he remembered one engine that was doing the best duty which had the steam cut off at about 1-10th stroke. There could be no doubt however that generally it was objectionable to cut off the steam very early in an engine that was heavily loaded: for this produced a serious blow on the piston, which did the engine a great deal of harm, by straining and sometimes even fracturing the machinery, which was consequently required to be of very great strength. Hence it was important to know that 1-4th stroke was the practical limit to which the expansion was carried in the actual working of the single cylinder engines described in the paper.

Mr. F. J. BRAMWELL enquired what was the amount of the working expenses per horse power of the engines at the East London Water Works, at the ordinary price of coals in London.

Mr. GREAVES replied that the engines worked at the rate of 12*d.* per horse power per day of 24 hours, including all expenses and every kind of repairs, but not interest on capital.

Mr. F. J. BRAMWELL asked what would be about the original outlay of capital for such engines, that is the first cost of the engine itself and of the engine house, but exclusive of the boilers and the boiler house; and also what was the horse power of the work done: in order that there might be the means of knowing the proportion that the first cost bore to the horse power developed in these Cornish engines as compared with pumping engines having cranks and flywheels.

Mr. GREAVES said the power of a 100 inch cylinder Cornish engine working at a fair speed might be taken at about 250 horse power in the work actually done in the main beyond the pump: and the whole first cost of such an engine, with six boilers, chimney,

air vessel, stand pipe, and engine house complete, would be about £23,000 or £24,000. This was equivalent to nearly £100 per actual horse power of work done beyond the pump; but in these Cornish engines the term horse power was seldom used at all in statements of the work done, the duty being reckoned in millions of lbs. raised 1 foot high by the consumption of 1 cwt. of coal, according to the usual practice in Cornwall. The engine house included in the above cost would be one built on a handsome scale and exceedingly massive, enclosing the entire engine; but in Cornwall the house for such an engine was never carried beyond the "bob" wall upon which the beam is supported, and the outer half of the beam worked out of doors, thereby greatly diminishing the cost of the house: this had been done also in an engine put up recently at the Kent Water Works near London, where the pump plunger worked out of doors.

Mr. E. A. COWPER remarked that reference had been made in the paper to the loss that must arise from the top cylinder cover not having a steam jacket, since it was exposed alternately to the high temperature of the steam as it entered the cylinder at high pressure and to the low temperature of the expanded steam at the end of the stroke, and would thus cause some loss by condensing a portion of the steam at the beginning of each stroke: and he thought it was desirable that the piston also should be kept heated by steam, if this could be done conveniently, because the body of the piston must condense a certain quantity of steam at the beginning of the stroke, which, although it became evaporated again towards the end of the stroke, was deprived of its effect as steam in the earlier part of the stroke, and required a corresponding increase in the quantity of steam admitted to the cylinder for each stroke. He observed also that much of the pressure of the steam was commonly lost by wiredrawing it on admitting it to the cylinder, as the indicator diagram from the 80 inch cylinder showed a pressure in the cylinder of only 13 lbs. while the boiler pressure was 30 lbs. per square inch above the atmosphere.

Mr. D. ADAMSON remarked that the arrangement of the Cornish engines described in the paper appeared to involve a very large outlay in the first cost of the engine, in proportion to the amount of power

obtained, since the mean pressure of steam throughout the stroke was stated to be only 2 or 3 lbs. per square inch above the atmosphere. He thought the application of large cylinders with low pressures of steam was not an economical or advantageous mode of working; and that to get the greatest economy it was necessary to develop the largest amount of force from the steam side of the piston, instead of obtaining more than three quarters of the entire power from the exhaust side of the piston. Moreover the Cornish engine being single-acting, the whole power required for performing the work had to be put into the engine in one stroke, instead of being equally divided between the two strokes; and with so low a pressure of steam as was generally used, and an early cut off, a very large and expensive construction of engine had to be employed for performing a comparatively small amount of work. With pressures of 140 to 160 lbs. now employed successfully in locomotives, there seemed no reason why the required power should not be obtained in stationary engines by the use of much smaller cylinders, working double-acting, and steam of 100 or 120 lbs. pressure, which with suitable boilers would be easily practicable, while the engines would run steadier and would involve a much less extensive accommodation for housing them. At his own works he had had such an engine of about 42 indicated horse power working regularly for $8\frac{1}{2}$ years with 150 lbs. steam, and with a consumption of $2\frac{3}{4}$ lbs. of coal per indicated horse power per hour: and the first cost of the engine with boilers complete was not more than 20 per cent. of the outlay that had been mentioned of the Cornish engine.

As regarded the degree of expansion in the cylinder, he thought an early cut off was not desirable; for when there was a great difference between the pressure and consequent temperature of the steam at the beginning and end of the stroke, there was then also a great loss in condensation in bringing the cylinder up to the temperature of the initial steam before the piston was moved at all. He had found by experiment in a beam engine that with 60 lbs. steam the maximum economy was obtained when the cut off took place not earlier than 1-3rd stroke; but as the expansion increased with earlier cut off, the condensation increased also, and there was only the same work done

with a much larger expenditure of steam: and he had no doubt that all engines where the cut off was earlier than 1-3rd stroke lost a considerable amount of power by condensation of the steam in the cylinder. He therefore thought it was not desirable to carry expansion in one cylinder to any degree that would involve a greater change of temperature in the cylinder than about 30° Fahr.; and if a greater expansion were desired than was allowed under this limitation, it would be advisable to employ a second cylinder, and even a third if necessary, and also to superheat the steam slightly between the cylinders, to preclude all possibility of condensation in them. By thus increasing the number of cylinders and limiting the degree of expansion, the temperature of each would be kept much nearer to that of the steam throughout the stroke. At the same time a high speed of piston was required, since the absorption of heat was so rapid that the loss by condensation could not be prevented if the speed were low. The consideration of the pressure of steam, temperature of cylinder, and degree of expansion, was therefore of the greatest importance for keeping down both the working expenses of an engine and its first cost.

The single-acting engine on the Cornish principle had he thought some advantage over a pumping engine with crank and flywheel, in the fact that no power was required in the Cornish engine for keeping gearing in motion at each end of the stroke; a certain amount of percussive action was indeed necessary to overcome the inertia of the engine at the beginning of the stroke, but on the other hand the whole engine was brought to a dead stand at the end of every stroke by the whole effective power being completely absorbed in the work done in pumping. Moreover the single-acting beam engine with loaded plunger was clearly preferable to a single-acting crank engine; but with a double-acting engine with crank and flywheel, and with a higher degree of expansion, he believed more power would be obtained from a given consumption of fuel than could be got in the Cornish engine. For the purpose of driving machinery the Cornish engine was admitted to be altogether inapplicable, from the great variation in the power throughout the stroke: but even as a pumping engine he thought its real economy had been overrated, since the most economical results were said to have been attained with pressures of

only 25 or 30 lbs. above the atmosphere at the outside; and if this were the case, a still greater degree of economy might be expected to be obtained by the adoption of higher pressures of steam.

Mr. C. W. SIEMENS observed that the subject of condensation of steam in the cylinder was now becoming more generally understood than formerly; and the practical remedy which had been suggested, of superheating the steam before it entered the cylinder, had been attended with very beneficial results, especially in the case of marine engines. The relative advantages of superheating the steam were greatest in working it very expansively; hence expansive working might now be carried further with advantage than formerly.

The CHAIRMAN enquired what had been taken in the paper as the theoretical maximum of the effect that could be obtained from the consumption of a given quantity of feed water.

Mr. GREAVES replied that the theoretical maximum of effect had reference only to the particular point at which the steam was cut off in the cylinder, and was measured by the theoretical volume which the steam would finally occupy in being expanded with that degree of cut off under the total load of the engine. The volume of steam which would be produced at the pressure of the total load from a given consumption of feed water was known from experiment; and the further effect of expanding this steam in the cylinder was ascertained by means of the hyperbolic logarithm of the number of times it was expanded, which gave the theoretical final volume of the steam at the end of the stroke. This was taken as the measure of the maximum effect to be obtained from that consumption of feed water, under the given total load and with the given degree of expansion: and the actual effect obtained was similarly measured by the actual volume of the steam at the end of the stroke. The practical result of this mode of measurement was that in the engines at the East London Water Works the actual power developed was from 70 to 75 per cent. of the theoretical maximum, with the steam cut off at 1-4th stroke.

Mr. J. FERNIE remarked that the paper that had been read was one most useful to all employing pumping engines, and it was a great advantage to have complete statements of what had been done in actual work with the different constructions of engines. In pumping engines

with a crank and flywheel he did not think so high a pressure had yet been attempted as had been suggested, of 100 or 120 lbs. per square inch; the highest pressure yet employed in such engines was he believed not more than about 50 lbs. per square inch. At the Clay Cross Colliery near Chesterfield he understood a large pumping engine on the Cornish principle was now being erected to take the place of the small crank pumping engines previously employed there, and he enquired what was the size and cost of the Cornish engine in this case.

Mr. W. Howe replied that at the Clay Cross Colliery they had pumped a large quantity of water for several years past with six small non-condensing engines with cranks, working eight sets of pumps; but the result had been found not at all satisfactory. The pressure of steam in the boilers was not more than 50 lbs., but the engines were not worked very expansively. The coal used was of a very common quality, and therefore an economical result was not to be expected. It had now been determined however to do away with all the small crank pumping engines, and put up one large Cornish pumping engine instead; but the cost of this engine would be much less than that mentioned as the cost of one of the engines described in the paper. In the engine now being erected the cylinder was 84 inches diameter, with a stroke of 10 feet in both the cylinder and the pumps; and it was intended to raise a column of water 18 inches diameter and 600 feet height; consequently the effective pressure on the piston would be about 12 lbs. per square inch. The entire cost of this engine, with a wrought iron beam constructed with two large wrought iron plates one on each side, would be about £4500, including the house, boilers, chimney, and everything to the outer end of the beam: a very different cost from that previously named. The boilers used were common cylindrical boilers, which had been found best suited to the collieries and better for the purpose than the Cornish boilers, as they did not require such skilled mechanics to keep them in repair and would therefore be worked with greater economy. He had no doubt that from £7000 to £8000 would cover everything, including sinking the shaft and putting in the pumps and the engine. The engine house was a substantial brick building with solid ashlar beam wall up to the level

of the cylinder pillar, which was likewise of ashlar stone ; but it was only half a house, extending no further than the beam wall.

Mr. E. REYNOLDS observed that the cost of the engine alone without the pumps or house was about the same for a Cornish engine as for an ordinary beam engine with crank and flywheel ; and might be taken roughly at about £40 per inch diameter of the cylinder in engines with 80 or 100 inch cylinders, say £4000 for the engine described : and this would be equivalent to £40 per horse power for a crank engine of 100 commercial horse power ; but such an engine would be capable of working at about $2\frac{1}{4}$ times its nominal power or 250 actual horse power.

Mr. E. A. COWPER enquired what was the cost of the engine alone without the boilers, and the weight of the engine.

Mr. W. HOWE replied that the cost of the engine alone was about £3000 : the total weight with a cast iron beam was about 140 tons, exclusive of boilers and fittings to boilers ; but with the wrought iron beam that had now been adopted for the engine the weight would be somewhat less.

Mr. E. SLAUGHTER asked whether Mr. Greaves had had any opportunity of making a comparison of the duty performed per cwt. of coal in the single-acting Cornish engine and in a double-acting engine with crank and flywheel. He believed a general impression prevailed that the Cornish engine possessed some special virtue as a pumping engine, in comparison with the flywheel engine ; and wished to know whether it showed in practice any advantage in duty.

Mr. GREAVES replied that with the commonest coal that could be bought he believed the Cornish engines described in the paper were yielding about 70 millions duty per cwt. of coal (70,000,000 lbs. weight lifted 1 foot high) ; and with a flywheel engine of the same size he thought the duty obtained would not be above 50 millions ; but he had not had an opportunity of trying a first class flywheel engine that had been brought up to the same degree of efficiency as the Cornish engine.

The CHAIRMAN observed that it was desirable to bear in mind the different circumstances under which single-acting or double-acting engines were applicable. The result of his own experience with the

two classes of engines was that the double-acting engine would as a rule do three times the work that could be done by a single-acting engine, for the same size and weight of engine. The double-acting engine used the steam on both sides of the piston, and worked always at least one half faster and sometimes twice as fast as the single-acting engine. Hence for the same power it was much more economical in first cost than the single-acting engine. But the relative advantages must be looked at with regard to the cost of fuel in working, the interest on capital, and the extra cost of wages which was consequent upon employing a single-acting engine instead of a double-acting engine. In general the employment of a single-acting engine necessitated the payment of 30 per cent. more in wages than was necessary in the case of a double-acting engine, the former requiring a better class of men to attend to it. He was not able to understand the reason for reverting to the Cornish engine in place of the previous crank engines for pumping at Clay Cross; for the single-acting engine involved a much larger cost in the construction of the building, and a much greater weight of material in the engine itself for the same power; and it was completely out of place where fuel was cheap, as was the case in many important instances where engines were used for pumping, costing in one instance within his own knowledge only 9d. per ton. In other cases where fuel cost as much as 30s. per ton, it became a very important matter to consume the smallest quantity possible, and therefore it was then best to employ the single-acting Cornish engine; because in a double-acting engine with a smaller cylinder the passive resistance or friction of the machine was considerably greater per square inch on the piston. But between these two extremes all varieties of intermediate cases arose, and it frequently became a question of very great nicety to determine which was the proper engine to be employed. Moreover commercial considerations sometimes rendered it advisable to pay more in annual expenses for the purpose of economising the first cost of the engine; and here it was more desirable to employ the double-acting engine. No general determination therefore could be arrived at for the use of either engine, but it was highly important that all the facts connected with each should be elicited and discussed. At the Main Drainage Works at Greenwich

the members had had an opportunity on the previous afternoon of seeing the double-acting engines employed for pumping the sewage, which he believed would be found more advantageous under the particular circumstances of the case than single-acting engines would have been, because the lift was very low and variable: but the case of the East London Water Works referred to in the paper was of an entirely different character, the lift being considerable and rendered uniform by means of a stand pipe, and it was therefore more desirable in that case to use single-acting engines than double-acting.

He proposed a vote of thanks to Mr. Greaves for his paper, which was passed; and expressed a hope that he would continue the observations hitherto carried out upon the working of the engines, and communicate the further results of his observations on a future occasion.

The following paper was then read:—

ON THE MANUFACTURE OF HEMP AND WIRE ROPE.

BY MR. CHARLES P. B. SHELLEY, OF LONDON.

Ropes are mainly constructed either of the fibres of the Hemp plant (*cannabis sativa*) or of Iron Wire. Other vegetable substances and other metal wires are also used; but in the present paper only the two important manufactures of hemp rope and iron wire rope are referred to: and as the treatment of the hemp fibres and manufacture of them into rope is quite different from the formation of iron wire rope, the subject naturally divides itself into two branches.

Hemp Rope.—Of the other substances besides hemp which have been found useful and profitable for rope making, the most important are—“manilla”, the fibres of which are obtained from the bark of a wild species of banana grown in the Philippine islands, manufactured into a rope commonly known as “white rope”; jute, grown in Bengal, the fibres of which are used for adulterating hemp; cocoa-nut fibre for inferior ropes; Indian hemp or “sunn”, the high price of which however keeps it out of the market; and Spanish grass or “esparto”. Of these “manilla” is the most common substitute for hemp. The machinery employed for manufacturing any one of these several fibres into rope is similar with slight modifications to that employed for hemp. The intestines, hide, and hair of animals are sometimes used for rope for special purposes; and the Romans are said to have formed ropes by binding together rushes (*junci*), whence the name “junk” for cable is believed to be derived. A variety of specimens of hemp and of other fibres, together with ropes of different makes, are exhibited, which have been kindly furnished to the writer by Messrs. Wright of Millwall. The manufacture of hemp ropes is still carried on by hand, the ingenious machinery invented for the purpose by the late Capt. Joseph Huddart, and for some time employed at Deptford dockyard, having been abandoned and the old plan of hand making again reverted to.

The hemp plant from which the fibre is derived consists of a woody cylindrical stem, surrounded by a fibrous peel held together by a glutinous substance, the whole being protected by a fine epidermis or skin. The fibrous part, which is the portion used in the manufacture of ropes, is strong, flexible, and tenacious; but the woody core and the external skin are useless, and it is necessary that they shall be separated from the fibres. This is effected by "retting", that is by soaking the hemp stalks in water and allowing fermentation to take place, thus rotting the woody and glutinous parts and leaving the fibres free. The hemp is pulled up by the roots, and the flowers and leaves stripped off, and it is then immersed in a pond or running stream where it is allowed to remain until fermentation takes place, the time of immersion being dependent upon the degree of humidity and temperature of the atmosphere and also upon the quality and growth of the stalks. There are many objections however to this system of retting; the principal is that the stalks not all being of the same strength of growth, and also occupying different positions in the immersed heap, some are liable to suffer from decomposition and be weakened while others may not be sufficiently steeped, rendering it difficult in the processes which follow to separate the woody matter from the fibres, and thus rendering the hemp harsh and inelastic. Another serious objection is that the vapour arising from the putrefaction of the stalks renders the neighbourhood of the stream or pond where the retting is carried on unhealthy. Moreover this mode of retting unavoidably deteriorates and wastes the fibre; for a single stem of hemp is said to be composed of 70 to 80 per cent. of wood and 20 to 30 per cent. of fibre, whereas the fibre obtained by the present method does not exceed 16 per cent. and falls as low as 12 per cent., the remainder being wasted in the retting. Several other modes of preparing the stalks have been tried, such as steaming them, treating them with lime water or alkaline solution, and also adding materials to the mass of soaking stalks with a view of inducing speedy fermentation; but generally these plans have failed and there is still room for improvement in this respect. After the stalks have been dried they are broken at a hand break or by rollers, and the woody part is separated by "scutching", somewhat in the same

way as in the case of flax. The hemp thus prepared is packed in huge bales, each bale of Italian hemp, jute, or manilla, weighing about $2\frac{1}{2}$ cwts.

In order to form the strongest rope out of a given quantity of material, whether hemp fibres or metallic wire, the fibres should be laid parallel alongside one another and secured at the ends, so that they may take any tensile strain put upon them in the direction of their length; the strength of such a rope will be equal to the strength of each fibre multiplied by the number of fibres in the section. Hemp fibres rarely exceed 4 feet in length, so that the above method of making a rope exceeding 4 feet in length will not apply to that material. In order therefore that the fibres may be securely and continuously connected together, they must be placed parallel to one another with the end of one fibre overlapping the end of its neighbour; and to prevent the fibres slipping from one another, friction is produced amongst them by twisting; but as the strength of the fibres is diminished when they are twisted out of the direction of the tensile strain which they are to sustain, no more twist should be given than is necessary to impart sufficient friction to prevent them from slipping and parting endways. It must be remembered that fibres of hemp, like metallic wires, have not the property of "felting", or uniting into one length by a kind of entanglement or matting together, in the manner common to the fibres of wool and other materials used in spinning. If a bundle of parallel fibres be twisted, those on the outer surface will be stretched and strained considerably more than those near the centre; and the further they are from the centre the more will they be strained. Hence in constructing cordage it is necessary to form or build it up gradually from small bundles. Thus the primary object of the rope maker is to get the longest, finest, and strongest fibres which can be economically obtained; and next to lay them in bundles parallel to one another and in continuous juxtaposition, giving them ultimately such a degree of twist that the friction amongst the fibres of the bundle is equal to their tensile resistance.

When the fibres are laid parallel and in continuous juxtaposition, they are said to form a "sliver"; and the sliver when twisted is said

to be converted into a "thread" or "yarn"; and a number of yarns laid parallel and in juxtaposition, bound round by an external "serving" of yarn to hold them together, form "selvagee" which is the simplest construction of rope. If each of the yarns in the selvagee bore its fair share of strain, this would be the strongest kind of rope; but the objection to its more frequent use is that the outside "serving" of yarn frets away and allows water to enter and rot the yarns inside. In order to overcome the objections to selvagee, ropes are made of "strands", each strand consisting of a number of yarns twisted together, the strands being again twisted into the rope; the class of rope depends upon the number of strands and their arrangement. The yarn is twisted in the process of manufacture by a motion to the left from the right, or contrary to the motion of the hands of a watch, producing what is termed in rope making a left-handed twist, being a spiral corresponding to the thread of a right-handed screw. The twist of each strand is in the opposite direction to that of the yarns composing it; and the twist of the rope itself is again in the opposite direction to that of the strands, or in the same direction as that of the yarns.

Ropes are commonly divided into three classes known as "hawser-laid", "shroud-laid", and "cable-laid" ropes. "Hawser-laid" ropes are composed of three strands twisted together; the number of yarns for each strand in different sizes of hawser-laid ropes is dependent on the diameter or number of thread of the yarn. "Shroud-laid" ropes are composed of four strands. "Cable-laid" ropes are composed of three hawser-laid ropes twisted together. "Cablets" are small cable-laid ropes measuring from 1 to 10 inches in girth; larger sizes are termed cables. Shroud and hawser-laid ropes seldom exceed 10 inches in girth. A core or "heart" is used in shroud-laid ropes; it is made of rope and is placed in the centre of the strands, running from end to end of the rope with the strands laid round it. In old worn out ropes the core is always found to be broken in consequence of the stretching of the strands; for the strands being twisted spirally and the core straight, the strands will give more under a load than the core, which cannot therefore be relied upon for adding strength to the rope; but it assists materially in keeping the strands in position

during the manufacture of the rope by hand. Flat hempen ropes are made of four or six ropes, each composed of three strands, and laid alternately to the right and to the left; these are stretched side by side and sewn through in a zigzag direction.

Before the hemp is spun into yarn it has to be freed from dust and hard knots, and the fibres combed so that they may be separate and parallel to one another. This process is called "Heckling", and is done either by machinery or by manual labour; the machinery for the purpose is similar to that used in the preparation of flax. When done by hand, each man is provided with two combs or "heckles", one coarse and the other fine. The heckle is formed of a number of straight sharp-pointed steel pins fixed with the points upwards in an inclined board; the length of the pins, their thickness, and pitch or distance from centre to centre, vary with the material to be heckled, those used for manilla being much finer and closer together than those used for hemp: the pins for heckling hemp are about 10 inches long and about $2\frac{1}{2}$ inches pitch centre to centre. The dresser after untying and opening one of the heads of hemp takes hold of the fibres at about the middle of their length and throws one end of them loosely over the pins, and pulls the bundle towards him; this is repeated until about half the length has been thoroughly combed by drawing through the heckles. The bundle is then turned end for end and the other half heckled in the same way, after which it is finished on the fine heckles. The hemp is now entirely free from knots and has a glossy silky appearance; it is distinguished as "long hemp" and is said to be "topped"; and the handful of hemp is then doubled in the centre and tied at the ends, in which state it is called "doll" and weighs about 2 lbs. The tow or fibres retained by the heckles are called "shorts", and if the shorts are to be worked into the yarn they are tied up with the bundle of "doll". The dresser applies a little oil occasionally to the points of the prongs for the purpose of reducing the friction; and in dressing manilla, soap is sometimes applied to the fibres for the same purpose, in addition to oiling the heckles. Each bale of Italian hemp, jute, or manilla, weighing $2\frac{1}{2}$ cwts. or 280 lbs., loses by heckling about 80 lbs. of "shorts" and 10 lbs. of waste, leaving 190 lbs. of "long hemp" from the bale. One dresser heckles in a day 8 cwts.

(finished weight) of St. Petersburg hemp, or 2 cwts. of manilla, or $1\frac{1}{2}$ cwt. of jute.

The next process which the fibres undergo is that of Spinning into yarns. Hand spinning is done on a long strip of ground called the rope walk, which is generally covered by a low roof: sometimes the shed has an upper floor with a low roof, and then the spinning is done on the upper floor and the other parts of the manufacture on the ground. The length of the walk and shed is about 1230 feet or a little over 200 fathoms, and the width about 30 feet. The tie beams of the roof are placed every 30 feet or 5 fathoms apart, and carry a row of hooks on the underside. That end of the walk at which the spinning machines are placed is called the "head" or "fore end" of the walk, and the opposite end is the "foot" or "bottom end" of the walk.

The Hand Spinning Machine, shown in Figs. 1 and 2, Plate 46, is formed of two cast iron frames with a band wheel A between them, driven either by a man at the winch handle at the back or by steam power. A band passing round the wheel passes over twelve wood rollers or "whirls" B, $1\frac{1}{2}$ inch diameter, as shown enlarged in Fig. 3, fixed on steel spindles about $\frac{3}{8}$ inch diameter which revolve in notches or bearings in the brass discs C screwed in the frames of the machine: the spindles are kept in their bearings by a riband of wrought iron screwed upon the outside of the frame. On the back end of the spindle is a shoulder, and between this and the brass disc is a loose collar, to take the pull of the yarns in spinning; the spindle is kept in by a finger D fixed on the back of the frame. The front end of the spindle is drawn out into a hook E. The notches in the brasses C, shown enlarged in Fig. 4, are for the purpose of forming fresh bearings for the spindles; there are eight notches in each brass, and when one notch is worn down the brass is turned to bring another notch round: when the whole of the notches are worn down a new brass is put in. The twelve hooks and "whirls" are set upon the semicircular upper part of the machine, and are made to revolve by the band which passes over them from the driving wheel A.

Each spinner before beginning to spin takes up a bundle of hemp sufficient in quantity to spin one "thread" of yarn of the required length; he places the "bight" or middle of the length of the fibres in front of him, and turns the ends round his waist, crossing them behind. If the "shorts" are to be worked into the yarn they are tucked below the bight. Each spinner carries in his right hand a piece of stout list. There are twelve spinners to each machine, one to each hook. The spinner draws from the bight or front of the bundle round his waist a sufficient quantity of fibres for the size of the yarn or thread about to be spun, thus forming a "sliver", which he twists with his fingers and hooks the bight of the sliver on to one of the revolving hooks of the machine. He then walks backwards towards the bottom of the rope walk, drawing the hemp from his waist and forming a sliver with his left hand, pulling some of the fibres back if they come forward too quickly and drawing some forward if there are not enough to keep up the required size of yarn. The sliver passes through his right hand, with which by means of the piece of list he firmly grips it, so as to "form" the yarn. The spinner thus prepares the sliver and forms the yarn, while the machine gives it the twist. Care must be taken not to place the ends of one set of fibres too near to the ends of the next set, not giving them sufficient lap, otherwise the yarn will part by the fibres slipping endways from one another; and also to keep the fibres even and regular in thickness, in order that the yarn may be of equal strength throughout. The spinner's pace in walking backwards must be uniform and in accordance with the speed of the revolving whirls. The speed of the whirls and the amount of twist of the yarn is dependent upon the quality of the rope to be manufactured.

The twelve spinners are divided into three sets of four each; four risers, four middlemen, and four leaders. The four risers work from the four hooks on the left side of the machine, the four middlemen from the four middle hooks, and the four leaders from the four hooks on the right of the machine. All the twelve spinners start at once from the machine in the morning. The four risers spin down the walk a yarn 1-3rd of 160 fathoms long, and then stop, while the middlemen and leaders continue to spin past them. The four yarns of the risers

are now unhooked from the whirls by a man at the top of the walk, and are passed each through a hole F in the frame of the spinning machine, Fig. 1, Plate 46, to a reel at the back, upon which they are wound; the men at the bottom end of the yarns still hold on so as to prevent the yarn from untwisting, and follow it up to the machine as it is wound on to the reel. They then twist the ends of these yarns on to one of the holding pins G on the cross bar of the machine frame, and start spinning again with four fresh yarns which they will this time spin down to the whole length of 160 fathoms before stopping. The four middlemen spin down the walk a yarn 2-3rds of 160 fathoms long, and then stop, while the leaders still go on and pass them. Their four yarns are taken off the hooks of the machine and spliced on to the ends of the four yarns which were left on the holding pin by the risers; the yarns of the four middlemen are then wound on to the reel, the men following them up the walk and fastening the ends on to one of the holding pins: the middlemen then start fresh yarns of 160 fathoms length and spin down the walk. The four leaders spin down the walk a yarn 160 fathoms long, and then they also stop, and their four yarns are taken off the hooks and spliced on to the ends of the four yarns left on the holding pin by the middlemen; the yarns of the leaders are then wound up on the reel, followed up by the men. So they go on till breakfast time, the three sets of men never being up at the machine together, and never more than four being there at one time, so that the three sets are always separated. After breakfast the risers commence with the 2-3rds lengths and the middlemen with the 1-3rd lengths, and thus the quantity of yarn spun is equalised between them.

As the spinner proceeds down the walk he tosses the yarn with his left hand on to one of the hooks in the rafters in order to support it; and in coming back he jerks it off again. The distances of 1-3rd, 2-3rds, and 160 fathoms are chalked on the side of the shed, and as the spinners of each set come to the distance they shake their yarns and thus signal to the man at the machine for the yarns to be unhooked and reeled up. Each spinner is paid in London 9d. for spinning six threads or yarns, each 160 fathoms long; this is called "one quarter's work", and each spinner spins four threads in an hour.

The yarns are distinguished and designated by their size or number of thread, every size being numbered ; the ordinary numbers, beginning with the coarsest yarn and going to the finest, are 18, 20, 25, 30, and 40. No. 20 is the most usual size and is employed for "London staple cordage"; No. 25 is used for government yarns, No. 30 for bolt rope yarns or the finest description of cordage, and No. 40 for whale lines. In spinning No. 20 size the "shorts" are always worked in with the "long hemp"; but for finer sizes, 25, 30, and 40, "long hemp" alone is used, in order that the yarn may be even and smooth. The size of the yarn is determined by the number required in each strand to make a rope of 3 inches girth with three strands ; thus the size of No. 20 yarn is such that 20 yarns in each strand will make a rope of 3 inches girth with three strands. No. 20 is said to be the usual "grist"; Nos. 25, 30, and 40, are said to be finer "grists".

If the cordage is to be tarred, it is done at this stage of the manufacture, before the yarns are formed into strands ; but the process of tarring the yarns will be described subsequently.

When the reel behind the spinning machine has been filled with the four lengths of yarns spun, it is taken to the Winding Machine, shown in Figs. 5 and 6, Plate 47, which separates the four yarns on to four separate bobbins A A, and also reverses the lay of the yarn end for end so that the fibres may lie in the proper direction for passing through the next process. Fig. 5 is a front elevation of half the length of the machine, showing two of the four winding bobbins A A ; and Fig. 6 is an end elevation. The bobbins are driven from the drum B which extends the whole length of the machine, by means of straps passing round the four riggers C C fixed on the vertical spindles that carry the bobbins A. The full reel containing the four yarns from the spinning machine is mounted on a temporary frame behind the winding machine, and the ends of the four yarns are led to the bobbins over a sliding bar D, which has a vertical reciprocating motion given to it by the cam E and levers F, for the purpose of filling the bobbins regularly and equally from end to end. Other forms of winding machines are used, but the principle of construction is the same in all. When the

four bobbins are filled they are replaced by empty ones, until the whole of the reel from the spinning machine is wound off upon bobbins. The four full bobbins are then taken away and placed vertically in a large wooden frame called the bobbin frame, which holds from 150 to 200 bobbins. Each bobbin contains about 14 lbs. of yarn.

The next process is that of twisting a number of yarns together into a strand, which is termed "Forming" and is done in the "forming" machine and in the shed covering the rope walk. Having ascertained the number or size of the thread that is of sufficient thickness to form the required strand, the number of yarns corresponding to that size of thread are selected; and the ends of the yarns of this size are drawn from the bobbins and brought in a converging direction to a square iron plate, called the "register" plate, perforated with a number of round holes. Each yarn is made to pass through a separate hole in the register plate, and the yarns all converge thence into one common point through the forming board, in which is a taper steel tube with a trumpet-mouthed taper hole through it. The hole in the tube varies in diameter for each size of strand and is selected by a gauge: the diameter of the tube for one of the strands for a rope of 3 inches girth is 8-16ths inch at the small end and 9-16ths inch at the large end, and for the strands of a rope of 2 inches girth it is 5-16ths inch at the small end and 7-16ths inch at the large. The convergent yarns are entered into the tube at the large trumpet-mouthed end, and are forced through, fitting tightly into the tube; they are thus squeezed together previously to being attached to the forming machine.

The Forming Machine for twisting the hemp yarns into strands is shown in Fig. 7, Plate 48. It is mounted on wheels and made to travel along the length of the rope walk by the endless rope A, called the "fly rope", which passes round pulleys at the top and bottom of the walk and acts as a driving rope, being driven by an engine. This fly rope takes a turn round the whelp wheel B, which gives motion by gearing to the drum C and the twisting hooks or "nibs" D for forming the strands. A fixed rope E called the "ground rope", made fast at the ends of the walk, is coiled round the drum C, so that by the revolution of the drum the machine is made to

travel along the walk. During the travel of the machine the yarns hooked upon each nib are drawn out and twisted together into a strand; each nib taking the number of yarns required to form the strand. The speed of revolution of the hooks is regulated according to the kind of rope into which the strands are to be made; and the great object is to adjust the rate of travel of the machine in relation to the speed of the hooks so that the strands may receive the proper amount of twist in a given length. For this purpose the staves of the drum C which gives the travel of the machine are made capable of being shifted to or from the centre of the drum by means of adjusting screws, so as to diminish or increase the rate of travel.

In the next process the strands are "laid" into a rope by two "Laying" Machines, one at the upper end of the walk and the other at the lower end, shown in Figs. 8 and 11, Plates 49 and 50. In this process, instead of being twisted together as the yarns are in the previous "forming" process, the strands are placed or "laid" in their spiral position in the rope without being twisted. The laying machine at the upper end of the walk, Fig. 8, Plate 49, is fixed, and the three strands to form the rope are attached to the hooks D, which are made to revolve in a similar manner to those in the previous forming machine, by the fly rope passing round the wheel B. The lower end laying machine, Fig. 11, Plate 50, is left free to travel part way up the walk as the length of the strands becomes shortened by their being laid into a spiral in the rope. The wheel B here drives the two "forelocks" A A, to one or other of which the strands are made fast, according as the twist of the rope is to be right-handed or left-handed. The three strands for the rope are stretched tight along the length of the walk from the hooks D of the laying machine at the upper end to the forelock A of the lower laying machine, and are supported off the ground and kept separated by means of posts, called "samson posts", placed at every 5 fathoms length, with pegs to carry the strands. A taper piece of wood with three grooves, called the "laying top", shown enlarged in Figs. 9 and 10, Plate 49, is then inserted between the strands close to the lower machine, with its smaller end towards the forelock A, one of the strands lying in each of

the grooves. A transverse hole is made through the laying top, through which is passed the "top stick" or handle that the top is held by. The laying tops are made of various sizes according to the size of rope required: for a rope of 3 inches girth the top is 12 inches long, 10 inches diameter at the larger end, and 8 inches at the smaller. When the rope is more than $3\frac{1}{2}$ inches in girth, a "top cart" is used for supporting the top.

The laying machines being now put in motion, the revolution of the forelock A, Fig. 11, Plate 50, gives the twist or "hard" of the rope, while the laying top is firmly held by the handle from turning. The hooks D, Fig. 8, Plate 49, at the other ends of the strands are made to revolve in the opposite direction to the forelock A which is twisting the rope, so that the twist put into each of the individual strands at the point where they are united into the rope immediately behind the laying top is taken out again by the hooks at the upper end. The laying top is gradually pressed forwards by the closing of the strands upon one another behind it; its motion requires to be very regular, and it is prevented from moving forwards too fast by a "tail" or piece of rope attached to the top handle, which is coiled round the rope already twisted, and thus acts as a drag to the top. The two laying machines must be driven at exactly the proper speed relatively to each other, so that the twist put into the separate strands at the laying top may be exactly neutralised by the revolution of the hooks: otherwise if the hooks revolve too slow, they will partially untwist the individual strands, since the twist of the yarns in each strand is in the contrary direction to that of the strands in the rope; or if too fast, the strands will become twisted tighter. In order that the man holding the laying top may find out how the machines are working, whether too fast or too slow relatively to each other, he makes a mark on one of the strands close to one of the supporting posts: if the strands are being twisted too fast by the hooks of the upper laying machine, the mark on the strand advances towards the upper end of the walk, from the yarns themselves becoming twisted tighter together in each strand, whereby the length of the strand is shortened; but if too slow, the mark recedes towards the lower end, from the partial untwisting and consequent lengthening of the

individual strands. In laying the strands care is required with regard to the angle that the strands take. Should the tension on the strands become unequal, the required additional twist is given to those which have got slack by throwing out of gear those hooks of the upper laying machine to which the tighter strands are attached, and allowing the others to continue revolving until all the strands have again become equally strained. As the formation of the rope proceeds, the lower laying machine is gradually drawn up the walk by the shortening of the strands as they are laid together into the rope; and weights called "press weights" are placed on the frame of the machine to retard its motion and hold the rope tight enough during the laying. Formed strands of 180 fathoms length will make 120 fathoms of hawser-laid rope; the length of the strands will be determined by the length of rope required.

After the rope is taken off the laying machines, it is coiled on to a drum driven by steam power, being guided from end to end of the drum by the workman, whose hands are protected by a piece of old cordage twisted on the rope that is being coiled; this gives a polish and finish to the surface of the rope.

The previous description has referred only to ropes manufactured by hand. In the application of machinery to this manufacture, which is next to be considered, Mr. Cartwright appears to have invented the first rope making machine, which is the basis of others since constructed, his "Cordelier" having been brought out in 1792. Fig. 12, Plate 51, shows a sketch of the cordelier, which revolves on the horizontal shaft A, the laying top B serving as the bearing at one end of the shaft, having holes through it for the strands to pass through. In the discs C C fixed on the shaft A are centred the three horizontal spool frames D, carrying the spools E which contain the three strands to be laid together. As the cordelier revolves, the axes of the spools are preserved constantly parallel to themselves by the spool frames D being made to rotate on their bearings once for every revolution of the machine, by means of the pinions F on the spool frame bearings, and the counter wheels G gearing into the central dead wheel H, which is of the same diameter as the pinions F and is

held stationary while the shaft A revolves within it. The bearings at the other end of the spool frames D are hollow, for the strands to pass through to the laying top B. The strand is drawn off the spool by the pair of delivering rollers I, which receive motion by a worm wheel J on the axis of one of them gearing into the worm K within which the spool frame revolves. The drawing rollers L L draw the finished rope forwards as fast as it is made, and hold it from turning.

This machinery was a few years afterwards improved upon by Capt. Huddart, who constructed machines that were used for a number of years at the Deptford dockyard for spinning the yarns and for the manufacture of ropes and cables; and the author is mainly indebted for the following particulars of the construction of this machinery to a description and drawings given in the Professional Papers of the Royal Engineers by Mr. John Miers.

The Spinning Machine for converting sliver into yarn is shown in Figs. 13 and 14, Plate 52. Fig. 13 is a portion of the front elevation of the machine, showing four of the twelve spinning tubes A A; and Fig. 14 is a transverse section. The sliver, previously formed by another machine, is contained in the twelve cans B, which are driven rather faster than the spinning tubes A in order to give a slight preparatory twist to the sliver. The spinning tube A, shown enlarged in Figs. 15 and 16, has a spring clip C at the top, which grips the thread spun from the sliver and twists it with great rapidity, thus effecting the spinning. The thread so formed is then subjected to a considerable amount of tension by being drawn through the compressing jaws D, Figs. 15 and 17, and round the stretching pulleys E, F, and G, Fig. 14, the last of which is a double pulley with two grooves. The thread passes first over the pulley E, then under one of the grooves in the pulley G, over the pulley F, and again over the second groove of the pulley G, whence it passes away to a winding drum at the back of the machine. The main driving shaft of the machine is driven from the engine by a belt over the fast and loose pulleys H. There are three horizontal winding drums behind the machine, upon which the yarns are wound, each drum taking the yarns from four of the spinning tubes: the yarns are delivered upon the drums through holes in a longitudinal traversing bar, which is moved endways backwards

and forwards by a rack and pinion so as to guide the yarns from end to end of the drums alternately.

If the ropes are to be tarred the tar is applied to the yarns on leaving the spinning machine. For this purpose they are first wound off from the drum behind the spinning machine upon a winder called a "whimwam", made of a light open frame of iron and wood revolving on a horizontal shaft. The loose ends of the four yarns on the drum are attached to a hook at the right end of the winder, which is then turned by a winch handle to wind the yarns on, the yarns being guided on from end to end by a traversing plate with four holes in it which receives the required traverse motion from the shaft of the winder. On reaching the left end of the winder the yarns are doubled round the hook at that end, and the winch is then turned in the opposite direction, winding the yarns on till they reach the right end, where they are similarly doubled round the hook at that end, and the winding is then again reversed. When a sufficient quantity of yarn has been put on the winder, the hook at one end is taken out and the yarn is uncoiled from the winder, thus forming a long skein called a "haul", which is then coiled upon a small circular revolving platform called a "turntable", about 4 feet diameter, mounted on wheels. The haul of yarns is then taken to the tarring shed, and uncoiled from the turntable into a cauldron of tar heated by fire or steam; one end of the haul is lifted from the tar, and by means of a capstan is drawn through a sliding nipper or squeezer for the purpose of squeezing out the superfluous tar from the yarns. After the haul has lain for some time, the longer the better, the four yarns are separated and wound on to four bobbins by the winding machine previously described; and are then passed to the bobbin frame ready for being twisted into strands. Capt. Huddart did not make the yarns into a haul previous to tarring, but passed them from bobbins direct from the spinning machine through the tar and thence through nippers to the register plate of his registering machine about to be described. The length of a haul is 55 fathoms; it contains about 144 threads and takes about 20 minutes to pass through the squeezer from the tar cauldron, that is about 16 feet in a minute. The tar used

should be the best Archangel tar, of a good bright colour, and heated to a temperature of 212° Fahr. The usual proportion of tar remaining in the yarns is from one quarter to one fifth of the weight of the untarred yarns. The yarns when tarred ought to be of a bright brown colour.

The "Registering" Machine, shown in plan in Fig. 18, Plate 53, is for the purpose of twisting the yarns into a strand and winding the strand upon a drum as fast as it is formed. The whole machine revolves with rapidity on the horizontal bearings A B, being connected with the driving power by a sliding friction clutch at B. The strand enters through the hollow bearing A, which grips it tight and thus twists the yarns into the strand by its revolution. The strand is drawn in by the pair of drawing pulleys C, taking half a turn round each, and is delivered upon the winding drum D by the guiding frame E, which is made to move from end to end of the drum by means of a stud on the frame working in a spiral groove cut in the barrel F. The drawing pulleys C, winding drum D, and grooved barrel F are all driven from the spur wheel G gearing into a stationary pinion fixed to the plummer block in which the bearing A revolves. As each successive coil of strand wound on the drum D increases its diameter, whereby an increased tension would be thrown on the strand, a friction clutch is inserted at H in the intermediate shaft which communicates the driving motion from the drawing pulleys C to the winding drum D, in order to prevent the drum from overwinding the pulleys, the friction being adjusted to the exact limit of tension desired in the strand. The guiding frame E which delivers the strand from end to end of the winding drum vibrates on a centre at I, and its rate of travel is varied for different sizes of strand by changing the worm wheel J on the spindle of the grooved barrel F; the universal joint K allows of the driving worm being set at different inclinations for gearing into a larger or smaller worm wheel J.

The strand made by the registering machine is wound off the drum D on to a loose reel, so that when transferred to the drum of the spool frame in the laying machine it may lie the same way end for end as on the drum D, in which state it is ready for being laid into a rope. The length of the strand is measured by passing it over a pulley of definite diameter, to which is attached a counter with a dial

indicating the number of fathoms of strand that have passed over the pulley.

The Rope Laying Machine for laying the hemp strands into rope is shown in Figs. 19 to 22, Plates 54, 55, and 56. Fig. 19, Plate 54, is a general elevation; Fig. 20, Plate 55, a plan at the top, and Fig. 21 a sectional plan through the spool frames; Fig. 22, Plate 56, is a side elevation of one of the spool frames to a larger scale. The three spools A, Fig. 19, Plate 54, filled with strand from the registering machine last described, are carried in the vertical spool frames B, which are centered at top and bottom in the main frame C of the machine. The entire machine revolves round the fixed centre shaft, and is driven by the small bevil pinion D gearing into the wheel E at the bottom of the main frame C. The spool frames B are made to rotate on their axes during the revolution of the machine by means of the pinions F on the spool frames and the counter wheels G gearing into the dead wheel H, which remains stationary, being fixed on the centre shaft of the machine. If the pinions F were of exactly the same diameter as the dead wheel H, the spool frames would make exactly one rotation on their axes for each revolution of the machine, and the spools would be preserved constantly parallel to themselves while the machine revolved, so that the strands would be laid into the rope without any additional twist in the individual strands. But in order to ensure the yarns in each strand being thoroughly closed upon one another, a slight additional twist or "forehard" is given to each strand in the act of laying it into the rope, by making the spool frames perform rather more than one rotation on their axes for each revolution of the machine, since the twist of the yarns in each strand is in the contrary direction to the twist of the strands in the rope. The pinions F on the spool frames are therefore made of smaller diameter than the dead wheel H in the proportion of 13 to 14. From the spools A the strands are drawn off round the stretching pulleys II, as shown dotted in Fig. 22, Plate 56, which are driven by bevil gearing and pinions J from a dead wheel fixed on the centre shaft at the top of the machine, with counter wheels and pinions K similar to those at the bottom. The strand is pressed tight into the

groove of the upper stretching pulley I by the small tightening pulley L, Figs. 22 and 23. The spool A is retarded from unwinding too fast by a friction break which is adjusted to any degree of tightness required. The strands pass up through the hollow bearings at the top of the spool frames B and through the pinions K, and are curved over the oblique guiding rollers M, which are fixed at varying inclinations in order to prevent the strands from slipping off. The three strands then unite at the centre and are laid together into the rope by the revolution of the machine, each strand being laid into the rope with the required amount of "forehard" by the simultaneous rotation of its own spool frame in the contrary direction to the machine. The newly made rope is carried upwards to another machine, where it is stretched over and under three pulleys driven by steam power; and as it passes from the last pulley it is compressed by a roller kept against the rope by a strong steel spring. It is afterwards finally coiled away in a warehouse.

There were three rope laying machines at Devonport dockyard and they were calculated to make about 3000 tons of cordage per year of 313 days. Of this amount the largest machine would make 2000 tons of cables and hawsers of large size, the cables ranging from 14 to 24 inches girth and the hawsers from $7\frac{1}{2}$ to $12\frac{1}{2}$ inches girth; the second machine of intermediate size would make 700 tons of cable-laid ropes from 8 to 16 inches girth and hawsers from $5\frac{1}{2}$ to $7\frac{1}{2}$ inches girth; and the smallest machine would make 300 tons of cablets from $5\frac{1}{2}$ to $7\frac{1}{2}$ inches girth and shroud-laid ropes from $3\frac{1}{2}$ to 5 inches girth. The average cost including all charges of the establishment, engine power, repairs of machinery &c., is said not to have exceeded 17*s.* 4*d.* per ton of cordage made, when the whole machinery was employed to the fullest extent of its capability; the cost by hand at the same period being stated to be 24*s.* per ton.

The Strength of hemp rope varies considerably, and depends principally on the quality of the hemp from which it is made, the number of yarns composing the strands, and the manner in which the ropes are laid. The average strength of each yarn in hawser-laid ropes is found to be greatest with the smaller sizes of ropes. Shroud-laid

rope made with four strands is about one fifth weaker than hawser-laid made with three strands, on account of the additional twist or "hard" which is given to the shroud-laid; and cable-laid rope is about one third weaker than hawser-laid rope. The strength of these three different lays is therefore in the proportion of cable-laid 10, shroud-laid 12, and hawser-laid 15. The relative breaking weights of ropes made from the three most ordinarily used materials are stated to be as follows: taking the breaking weight of St. Petersburg hemp rope at 100, that of Italian hemp rope is 107, and that of manilla rope 73. Tarred rope is weaker than untarred, other circumstances being the same; for the quality of the tar seriously affects the strength of the rope. Hence the strongest ropes are hawser-laid or three-strand ropes made of untarred Italian or Russian hemp.

Wire Rope.—The second branch of the subject of the present paper is the manufacture of Iron Wire Rope, which although at first made by hand is now made exclusively by machinery; and the writer is indebted to Mr. Archibald Smith for kindly furnishing the information on this branch of the subject.

Wire ropes were used as early as 39 years ago for the supporting cables of a suspension bridge at Geneva; and also for the Freiburg suspension bridge of 807 feet clear span, erected 27 years ago. The wire ropes in the latter case, shown in Fig. 24, Plate 57, are constructed of twenty bundles or strands of straight iron wire 0.125 inch diameter, stretched parallel, forming a rope $5\frac{1}{4}$ inches diameter, and bound round with wire at 2 feet intervals.

The first form of wire rope regularly manufactured was made about 27 years ago, and was known as "Selvagee", shown in Figs. 25 and 26, Plate 57. It consisted of a number of hard or unannealed wires, of about 12 to 16 wire-gauge or 0.110 to 0.065 inch diameter, which were stretched parallel and bound together by a fine wire of about 20 wire-gauge or 0.036 inch diameter, wound spirally around; after which a "parcelling" of woollen list was also wound round in the contrary direction, with the edges lapped so as to cover the wires entirely: the rope was completed by a service of tarred yarn wound on in the contrary direction to the list. The

method of making the rope was simply to warp or stretch the wires at a uniform tension over two hooks set at the distance of the length of rope required to be made, passing the wires backwards and forwards over the hooks as many times as was necessary to make up the size required. A solution of india-rubber boiled down in linseed oil with a mixture of resin and tar was rubbed carefully into the body of the rope, previous to binding up; and after the binding wire had been wound on, the solution was again applied to the exterior wires to prevent oxidation, the process of galvanising being unknown or not practised at that time. The "parcelling" of list was also saturated with the solution, the yarn being tarred as usual. The binding and parcelling were always done by hand, before the rope was taken off the hooks; but the service of yarn was usually laid on by a machine for that purpose, though occasionally also by hand. The method of attaching the fittings, such as shackles, thimbles, and dead eyes, was either by forming an eye during the process of warping to receive them, or by inserting the end of the rope stripped to the wires into a conical socket attached to the shackle, and turning back the ends of the wires so as to prevent the rope being drawn out. But more generally the fittings were "turned in", that is the end of the rope was doubled round and "seized" or bound to the standing part. It will be seen that it was very difficult to splice this form of rope, owing to the absence of twist or "lay".

Ropes thus made were exceedingly rigid and non-elastic, but possessed greater strength than any other construction; in fact the entire strength of the wire was preserved. The "parcelling" and "service" added to the size, but not at all to the strength, being intended only for protecting the wires. The want of elasticity and pliability, together with the difficulty of fitting and the constant wear of the "service" of yarn, acted somewhat prejudicially against the introduction of this first form of wire rope on an extensive scale; yet it was used in the royal navy and mercantile marine, and also for suspension and tension bridges: for the latter purpose it is still used, especially in California, where a large number of wire rope suspension bridges are now being erected to replace those destroyed by the late floods.

The machinery for making these "selvagee" ropes consisted simply of the two hooks over which the wire was warped, which were attached to moveable posts set at the required distance asunder. The "serving" machine was a long wood trough extending nearly the entire length of the rope ground, having a revolving shaft at each end with a hook at its extremity, and carrying a fast and loose pulley, over which a driving band passed. The two serving hooks were driven at the same speed of about 400 revolutions per minute: and the shifting forks of the driving bands were connected by a cord extending throughout the length of the ground, so that the workman could stop or start the machine at any part. An ordinary serving mallet was employed for laying on the yarn, and was guided by the workman who also regulated the tension, the yarn being supplied from reels hung overhead.

The next description of wire rope was known as "Formed" rope, shown in Figs. 27 and 28, Plate 57, and was introduced about 25 years ago. It consisted of a number of soft or annealed wires, usually about 14 wire-gauge or 0.085 inch diameter, "formed" or twisted into a strand, but with little or no regard to regularity; and four of these strands were "laid" into a rope, though this number was not always the same. The number of wires was varied according to the size of rope required, and occasionally the size of wire was altered to suit circumstances. These ropes closely resembled ordinary hemp ropes in appearance. The twist caused by "forming" the strands remained in the wire as a permanent set, and the strands were "laid" together with an extra amount of twist or "forehard" in each strand, which was necessary to keep the rope together. Little or no injury was done to the wire by this process, owing to its being annealed, and also from the length of the twist of the wires in each strand, which was usually about 12 inches pitch; but it would be almost impossible to use hard wire in this manner.

The "formed" wire ropes possessed great pliability and some amount of elasticity; they were readily spliced and fitted, like ordinary ropes, and though not so strong as the "selvagee" wire ropes, they possessed many advantages and were more easily introduced. Their

adoption for rigging, incline, and traction ropes, became extensive; and this construction was the first wire rope used on the Blackwall Railway. The small size and soft nature of the wire used offered little resistance to exterior friction, and when employed as incline or running ropes they soon flattened and wore out. The irregularity with which the wires were "formed" or twisted into strands, frequently crossing and recrossing one another, and the great difference in the length of the wires as well as the short "lay" of the ropes, amounting to only $4\frac{1}{2}$ inches pitch, materially assisted to destroy them. Even when used simply as standing rigging, the wires frequently broke, and the broken ends stuck outwards to the danger of the sailors handling the rigging; and to prevent accidents they were served with yarn, like the "selvagee" rope, after having been "wormed", that is having a yarn laid in between each strand so as to alter the shape to a round form.

The "formed" wire ropes were originally made on the rope ground by the forming machine usually employed in hemp rope making, shown in Fig. 7, Plate 48. The wires were wound on bobbins placed in racks, just like the hemp yarns, and were led through the perforated register plate, called the "minor" plate, thence through the taper steel nipper or compressing tube, and were attached to the forming machine, which drew out the wires and twisted them together as it travelled backwards towards the other end of the ground. Having arrived there the machine was stopped, and the length of strand thus made was wound upon a large reel, ready to be placed in the laying machine; the use of the reel also enabled a longer length of strand to be made than one length of the ground. For laying the strands into rope, the required number of reels of strand, generally four, were placed in frames mounted on horizontal bearings and geared together. The strands were stretched along the rope ground, being supported and separated on trestles placed at intervals; and were brought together over a "laying top" at the other end of the ground, and attached to a revolving hook. Motion was given to the machine at one end with the four strand reels, and to the hook at the other end in the opposite direction, by means of a "fly rope" or endless driving rope, passing over whelp wheels

attached to the machine and the hook ; the laying top was carried by a workman, who thus regulated the amount of lay or twist. Afterwards the laying top was mounted on a carriage which travelled on rails, and was drawn forwards by another endless rope, called the "ground" rope, which was worked by the machine. This arrangement had the effect of more effectually regulating the lay. "Formed" wire rope is now made in the ordinary vertical machine, which is supplied with extra frames for carrying a large number of bobbins ; but for forming the strands the bobbin frames are fixed to the frame of the machine, and not revolving in it, and the wires are brought together through a perforated plate containing the required number of holes.

"Formed" wire ropes were at first well saturated with the solution before described ; but afterwards galvanised wire was used for making them. The admiralty still continue to use the "formed" rope entirely, though little is now used elsewhere. "Formed" ropes made of copper wire were used largely in the navy as lightning conductors, the size of the wire being about No. 20 wire-gauge or 0.036 inch diameter, and the rope was made of four strands laid round a small copper wire core. Smaller ropes composed of iron and copper wire were also used as sash lines &c.

In another kind of wire rope, which was sometimes made on the machinery above described for the manufacture of "formed" rope, the strands were composed of hard wires, usually not exceeding six in number, laid around a core of hemp or wire ; and these strands were again laid around a hemp core into a rope. But the objections caused by the rigidity of these ropes prevented any but small sizes being used for some years. Ultimately however these objections were overcome, and this construction has now almost entirely superseded the "formed" rope.

The first Flat wire ropes, made 26 years ago, shown in Figs. 29 and 30, Plate 57, were composed of from eight to twelve "formed" strands, with the twist alternately right and left handed, made of a number of fine wires usually about 18 or 20 wire-gauge or 0.050 to 0.036 inch diameter. These strands were placed in the position of the warp, in a loom of the ordinary form but greater strength, and were

woven together with a shoot of strong yarn. Very little twist was put into the strands, as the yarn when woven in kept them in form. These ropes were by no means durable, as the yarn soon wore out, especially at the edges; and their application was very limited.

Flat wire ropes were next made, about 25 years ago, of four or six "formed" ropes, each made of four strands "laid" very long, and alternately right and left handed; these were stretched together side by side and sewn through with six wires of No. 14 or 16 wire-gauge from side to side in a zigzag direction, as shown in Figs. 31 and 32, Plate 57. This was accomplished by carefully inserting a needle of dagger shape between the strands of the ropes, and so making a passage for the wires, which were carefully laid side by side. The round ropes thus bound together resembled the ordinary flat hemp rope in appearance. The process was tedious, on account of the care necessary to avoid penetrating the strands with the needle, which would do great injury to the rope. It was also important that the amount of "lay" or twist in all the ropes composing the flat rope should be exactly the same, otherwise the stretching could not be regular, and some of the strands were liable to be cut when the rope was set to work. With the machinery previously described perfect regularity could not be attained in this respect, and an unsatisfactory result was the consequence.

The next and last construction of wire rope, introduced about 24 years ago, is known as "Laid" rope, shown in Figs. 33 and 34, Plate 57, in which the strands were made of a few wires, seldom exceeding six, "laid" around a core of hemp or wire, the wires of the strand being entirely free from twist, each wire being simply "laid" in a spiral form without any twist in the wire itself, as shown in the diagram, Figs. 35 and 36, Plate 58. Six of these strands were again "laid" without "forehard" or additional twist into a rope, around a core generally of hemp. The size of wire usually varied with the size of the rope, as the total number of wires 36 was seldom varied. The wire was hard or unannealed; and by the system adopted in making, a uniform length was obtained with entire absence of twist. By this means the full strength of the wire was retained, and consequently the

rope produced was much stronger for the same weight. An increase in size is however caused by the introduction of the hemp cores, which amount to 1-7th of the entire bulk in the case of ropes with six strands of six wires each, the construction now usually adopted.

These "laid" wire ropes, though not so pliable or strong as "formed" ropes, possess many advantages, especially when employed as incline ropes, the hardness and increased size of the wire giving greatly increased durability; and as the prejudice against wire ropes had been partially removed by the introduction of the "formed" ropes, the present "laid" ropes soon began to be extensively used; and within the last few years, since the expiration of many patents formerly existing, the manufacture has increased to a remarkable extent. Wire strand has lately come into extensive use for fencing, very large quantities being exported for that purpose for the Indian railways.

Flat wire ropes also are now made with strands composed of hard wires "laid" together, instead of "formed" as previously, these strands being again "laid" into ropes without any "forehard" or additional twist, and the ropes are then stitched together as previously described. Lately instead of several wires laid side by side being used for stitching, three or four strands have been substituted, each strand containing three wires laid together; the advantage of which is that though several of the single wires may be worn through, the strand still holds the rope together; yet in neatness of appearance the single wires have the preference.

The machinery used in the manufacture of "laid" strands and ropes originally consisted of the ordinary machinery used on rope grounds for laying or closing hemp ropes, the machines at each end of the factory being speeded alike, as previously described.

The next form of machine adopted had simply one hook, mounted in bearings on a fixed frame, and driven by hand or power, to which all the wires composing the strands were attached; these were stretched along the ground, supported at intervals on trestles, till they reached the other end, where they were hooked on to swivels or "lopers". Attached to the lopers were cords passing over pulleys

and having weights suspended from them, so as to regulate the tension of each wire and also allow for the shrinkage of the rope in the process of making. When the hook was set in motion, the twist in each wire traversed the entire length of the wire, and escaped at the end by means of the "loper" or swivel. A perforated plate or "laying top" was used, carried by a workman along the ground, regulating the amount of "lay" or twist.

The next machine used, shown in Fig. 40, Plate 59, was a modification of Huddart's hemp rope laying machine, previously described and shown in Fig. 19, Plate 54. In these machines the operation went on continuously until the required length of strand or rope was made, giving rise to the name of "endless" machines; they were also called "vertical" machines, because the main frame carrying the spools revolves on a vertical axis. The first modification of this machine for making wire ropes consisted in altering the gearing for working the spool frames B, so that no additional twist or "forehard" was put in the wires as in the strands of hemp ropes, the pinions on the spool frames being now made of exactly the same diameter as the central dead wheel, as shown in the diagram, Fig. 38, Plate 58, causing the spool frames to make exactly one rotation on their axes for each revolution of the machine. Machines of this description were also made to work on a horizontal axis instead of a vertical one; and a balance weight was sometimes attached to each spool frame in the horizontal machines, which by its gravity prevented the spool from twisting the wire and rendered gearing unnecessary for the purpose; but the speed of these machines was limited in consequence.

The next form of machine was that known as a "compound" machine, for producing the entire rope finished at one operation; and may be described as consisting of six stranding machines, like that last described, all mounted on one large frame and revolving horizontally, the necessary motion being given to the machinery to lay the wires into strands and then the strands into rope, without producing any twist in the individual wires. This machine, though a mechanical success, was a commercial failure, and was soon abandoned for the simpler and cheaper plan of first making the strands and then laying them into ropes on separate machines.

Next some modification was made in the vertical machines, shown in Fig. 40, Plate 59, in the means of preventing twist of the wires during the laying, by employing a centre crank or eccentric and four outer cranks on the spool frames B, as shown in Fig. 40, and in the diagram Fig. 37, Plate 58; and also by substituting chain wheels and pitch chain, as shown in the diagram Fig. 39, Plate 58. Machines were constructed with 36 spools on the revolving frame, connected by cranks to the centre crank; and ropes were thus made with that or any smaller number of untwisted wires in each strand; but this description of rope was rarely used.

In all the vertical and horizontal endless machines that have now been described, all the spools were mounted in one set on a single large revolving table, thus revolving all in one plane; and during the process of laying, the whole weight of the material had to be carried round a circular track varying with the size of the machine from 10 to 40 feet, one revolution being necessary for every lay put into the strand or rope, the lay varying from 1 inch to 18 inches or more in pitch, according to the size of rope. Machines of this construction were therefore necessarily limited in their speed. Lately however machines have been constructed with the spools arranged in two sets of three each, on two tables one below or behind the other, the spools thus revolving in two planes; whereby a somewhat increased speed was attained, as the diameter of the revolving tables was reduced. Yet still the spool frames had to be carried round the common centre and caused to rotate on their own centres once for every lay.

The method of joining the lengths of wires was in the first instance by twisting the ends together: afterwards, in the manufacture of "laid" strands, by "tucking", that is cutting out the hemp core about 12 inches from the end of the wire that has run out, and inserting in its place the end of the new length of wire; the rest of the wires are then "laid" up on the new wire as a core for a length of 6 inches, when the new wire is brought out into its right place and the remaining 6 inches of the old wire passed in as the core, on which the laying is again continued till the end of the wire is reached; the proper hemp core is then replaced, and the process of laying resumed as before. Some manufacturers prefer to braze or weld the ends of

the wires together for joining the lengths, wire as small as No. 16 wire-gauge or 0.065 inch diameter being welded by experienced workmen by means of a common portable forge.

An improved construction of wire rope machine has subsequently been introduced, in which the bobbin frames and bobbins are placed one behind another all in the axis of the revolving frame, and remain stationary in that position while the frame alone is made to revolve. By this machine a greatly increased speed is attained, and it is considered that better work is produced. The rate of production is also much increased, as much as 10,000 yards of strand having been made per day of ten hours, instead of only 2500 yards, the usual amount made by the ordinary form of machine.

This machine, the invention of Mr. Archibald Smith of London, is shown in Figs. 41 to 44, Plates 60, 61, and 62. Fig. 41, Plate 60, is a general side elevation of the entire length of the machine. Fig. 42, Plate 61, is a side elevation of one portion or compartment of the machine, to a larger scale and partly in section. Fig. 43, Plate 62, is a transverse section, and Fig. 44 an end elevation at the front end of the machine.

The bobbins A A, Fig. 41, Plate 60, are here all arranged in a horizontal line one behind another, in the axis of the revolving frame of the machine. The revolving frame is composed of a number of disc wheels C C, framed together by three long bolts D, Figs. 42 and 43, passing through holes near the edges of the discs and through strong iron distance tubes with collars at each end, which are all turned accurately to one length. Eight discs C C, Fig. 41, are thus framed together by the three bolts, and separated by the distance tubes, forming seven compartments of the machine, each containing a bobbin of wire A. The last disc at the back end of the machine forms part of a three-speed cone pulley E, by which the entire frame is made to revolve, being supported and steadied sideways at every alternate disc by the three rollers F, Fig. 43. The bobbin frames B B are centred in the revolving discs C, and have a weight G suspended from their underside, sufficient to overcome the friction of the bearings and prevent the bobbin frames from revolving with the machine.

The front end of each bobbin frame B, Fig. 42, Plate 61, has a hollow steel stud or "nipple" I, carefully bell-mouthed; and the back end has a solid stud H. Each stud works in a boss cast on the disc C, having a clear hole right through the centre for the wire to pass through; and the boss on the front side of the disc has a large gap J, for the wire to pass out from the centre. The wire from each bobbin A, shown by the strong black line, is drawn off through the bell-mouthed stud I and the centre of the disc C, and is then taken round the leading pulley K, Figs. 42 and 43, which is fixed on the framing bolt D for the purpose of enabling the wire to clear the bobbin in the next compartment. The wires pass through holes in the discs C on either side of the framing bolts D, as seen in Fig. 43; and on reaching the front compartment of the machine, all the six wires from the six bobbins A, Fig. 41, are led round three pairs of leading pulleys K, and thence through the holes in the front disc, Fig. 44, through the laying plate L, Fig. 41, and over the laying top M. The laying plate L is attached to the front disc of the machine, and has a slot in it for each wire to pass through. The laying top M fixed in front of the laying plate is simply a cast iron block with the required number of scores or grooves for the wires. The front bobbin N, Fig. 41, in the first compartment of the machine, carries a seventh wire to form the core for the six external wires, which is led off through the centre of the front disc and through a hole in the centre of the laying plate L and laying top M. The tension or "temper" of each of the seven wires is regulated to the exact amount required by a friction break O on the spindle of each bobbin, Fig. 43, Plate 62. The bearings of the spindle in the bobbin frame B are provided with spring caps, to facilitate changing the bobbins.

The six wires are all brought together at a point immediately in front of the laying top M, Fig. 41, Plate 60, where they are all laid round the core by the revolution of the machine, the bobbins A remaining stationary with the exception of their unwinding motion as the wires are drawn off; each wire is thus laid into the strand free from twist in itself. The strand thus made passes between the nipping rollers P, Fig. 44, which have a series of scores of different diameters to suit various sizes of strand or rope; the lower roller turns on

a fixed stud, and the upper one on a weighted lever. The strand is then led half round the indicator sheave R, Fig. 41, which has a counter attached to indicate the number of yards or fathoms made. Thence it passes backwards alongside the machine to the draw-off wheels SS at the back end; these are V grooved wheels of equal diameter, round which the strand passes in a figure of 8 course, as seen in Fig. 41, being pressed tight into the groove of the second wheel by the tightening roller or jockey wheel T, which prevents the strand from slipping from any accidental cause. The draw-off wheels S are driven from the driving pulley E by intermediate bevil gearing, with a change wheel by which the speed of the draw-off wheels is regulated in proportion to the speed of revolution of the machine, whereby the lay of the wires or pitch of the spiral in the strand is determined. The strand finally leaving the machine from the draw-off wheels is wound on a bobbin, ready to be placed in a second similar machine to be laid into rope. In this second machine the revolution of the laying apparatus is in the opposite direction while that of the draw-off wheels is in the same direction as in the first machine, in order to make the lay of the strands in the rope contrary to that of the wires in each strand. From the second machine the rope is coiled on a reel, or in case of its being a long length it is sometimes coiled down direct into railway trucks &c. for transportation.

In this machine, instead of the bobbins and bobbin frames, which sometimes contain half a ton weight each, being carried round the common centre of the machine, sometimes describing a circle of 15 feet diameter, and also rotating on the axes of the bobbin frames once for every lay in the rope, the same result is attained without any motion being given to the bobbin frames. This is an important advantage, because in course of working some of the bobbins are full while others are nearly empty, and in the case of the old machinery a great strain is thereby thrown on the parts of the machine from the variation in weight; while in the construction just described the equilibrium of the machine is never disturbed. In addition to this, great regularity of lay results from the wire being free to unwind, and from the absence of the extra tension that was necessary to prevent the wire being disturbed when rapidly carried round in the old machine. The stationary position of

the bobbins enables the workman to see what is going on, and no entanglement of the wire takes place as is frequently the case in other machines.

About 35,000 miles of the covering strands of the Atlantic telegraph cable were made in this machine; and likewise about 14,000 miles of the hemp-covered strands of the Toulon and Algiers cable. It is also extensively used in the manufacture of wire ropes.

Steel wires are now extensively used in the manufacture of wire ropes, being found to possess twice the strength of the best charcoal iron wire; while the skin of the wire is of such remarkable hardness as to resist a very great amount of friction, and the wire has a toughness equal to that of copper. A compound hemp rope is also now made by inserting a wire in the centre of each yarn, and making these yarns up as an ordinary hemp rope.

A number of specimens of hemp and wire ropes were exhibited, illustrating the several constructions described in the paper; and also working models of some of the rope making machines, lent for the occasion from the South Kensington Museum. A working model was also exhibited and shown in action of Smith's wire rope machine described in the paper.

Mr. SHELLEY thought it was highly important that the reasons should be ascertained which led to hand making being reverted to in the manufacture of hemp ropes, in place of the beautiful machinery invented for the purpose by Capt. Huddart and used for some time in Deptford dockyard; he had been unable himself to ascertain why the

machinery had been given up, or what were the exact defects experienced with it. The basis of all the machines, both for hemp and wire ropes, seemed to be Mr. Cartwright's cordelier invented at the end of the last century.

Mr. B. FOTHERGILL believed that one reason of the want of success of the machines for the manufacture of hemp ropes was a defect in the preparation of the material by the machinery, which did not produce a uniform thickness of thread; and the want of uniformity of thread resulted in unevenness of the strands made from the yarns, and consequent unevenness in the ropes themselves. Also wherever there was a small part in the thread, the twist all ran into that particular place, and the thicker parts of the thread did not get twisted enough; so that when a strain came upon the rope, the thicker parts of the threads gave way and were drawn out and the strain was all left to be borne by the smaller parts, and breakage was the consequence. Another defect in the machines was that no provision was made for laying exactly the same length of yarn upon each bobbin: this might readily be done by a measuring apparatus such as was ordinarily applied in cotton machinery, and then the bobbins would all be empty at the same time, and there would not be a heavy full bobbin on one side of the revolving frame of the machine and a light empty one on the other. In some hemp rope machines also there had been a defect in the arrangement for giving uniform motion to the twisting of the different strands when they were being laid into the rope. He thought the paper that had been read was one of a very interesting and instructive character: with regard to the manufacture of wire rope, he believed the hand method which formed the basis of the manufacture had its origin in the Hartz mountains.

Mr. A. SMITH remarked that in wire rope machines the inequality of weight arising from full and empty bobbins on opposite sides of the stranding machines was inevitable in the previous constructions of machines; for the wire was necessarily supplied to the machines in bobbins which would not contain the whole length of wire required for the entire strand, and it would be very unwise to let all the bobbins empty at once and all the joints come at one part of the strand. The bobbins therefore inevitably emptied at different times in the stranding

machines; but in the rope machines they all emptied simultaneously, since each bobbin contained the exact length of strand required for the whole length of rope.

Mr. SHELLEY enquired whether the defects that had been mentioned in the manufacture of hemp ropes had been overcome in the machine shown in the American department of the Exhibition, where the yarns were taken in at one end and twisted into strands, and the strands were then laid into a rope which came out at the other end of the machine. This machine was now at work, making ropes of half an inch diameter.

Mr. B. FOTHERGILL said the defects he had mentioned were not entirely overcome in the machine referred to; but the main defects lay in the preparation of the material before it was spun into yarns. In the treatment of flax or cotton the raw material was first got into a slivered form, and was then passed through a series of rollers, taking care not to destroy the fibres, but to draw and lay them parallel side by side; and in order to get uniformity of thread in spinning, the fibres so drawn out were then doubled again and again as many as twelve or thirteen times in the case of fine cotton spinning. Without this doubling it was impossible to obtain uniformity in the thread, and the defect that he had referred to in the manufacture of the threads for hemp ropes arose from the want of a sufficient number of doublings, so that in spinning the yarns there was a want of uniformity in the thickness; and in forming the strands these yarns were only congregated together, whether thick or thin, in a sufficient number for the required size of strand. The only approach to doubling was the twisting together of the yarns into the strand; but the doubling ought to take place in the raw material, so as to secure a uniform thickness of thread, and then the ropes would no doubt stand a much greater tension.

Mr. F. J. BRAMWELL remarked that in 1853 he had seen some hemp rope machinery at the Boston dockyard in America, where there was an arrangement in the preparing machine to equalise the amount of material taken in, by producing a retardation to prevent thick parts occurring in the thread; this was found to work well, and he had thought the difficulty on that score had been thereby overcome.

Mr. J. FLETCHER observed that he had lately seen some new machinery which was now being tried at Chatham dockyard for the purpose of ascertaining the difference of strength and pliability between hand and machine-made rope, made from the same hemp: and he understood the result already arrived at was that the machine-made rope was superior to the hand-made. In the manufacture of the machine-made rope the doubling system was adopted: six slivers of hemp were passed together through rollers, and two of these rollings were twisted together and spun into one small thread, and a strand was composed of a number of these threads twisted together.

The CHAIRMAN enquired whether the comparison of the hand and machine-made ropes was made weight for weight: and also what was the relative quantity of tar that was held by each construction of rope.

Mr. J. FLETCHER replied that the comparison of the ropes was made weight for weight and girth for girth; but the ropes were dry and no tar was used in them. He was not able to state the exact results arrived at with regard to the superiority of the machine-made ropes, but understood the general result was decidedly in their favour.

Mr. P. HAGGIE remarked that he had found in the manufacture of hemp ropes that in the preparation of the hemp the less it was passed through the rollers and doubled the better, if only the fibres were got something like straight and parallel: for after about the third time of doubling and passing through the rolling machine the gummy part of the fibre seemed to be destroyed by further manipulation, and although the fibres might be got more parallel, the yarn spun from the hemp was not so strong as when the hemp underwent less preparation. At his own works they had experimented a good deal upon the difference between hand work and machine work, and found that machine-made rope was about 25 per cent. stronger than hand-made rope of the same girth. The government test for yarn was 8 stone or 1 cwt. for a single yarn of the common size No. 18; but out of the same hemp machine-made yarn of the same size would bear from 12 to 18 stone; and he hoped they would ultimately be able to ensure a definite strength in all ropes of a given size and material. In

collieries, where machinery had often to be lowered into the pits and men's lives were dependent on the strength of the rope, it was particularly important to be able to rely on a certain definite strength throughout the entire rope.

Mr. B. FOTHERGILL observed that, with regard to the preparation of the hemp fibres, the doubling of the material was perhaps a point of less importance than that care should be taken to avoid breaking the fibres in the process of laying them side by side: if the doubling were too frequent or if the several pairs of rollers were not at the right distance apart from one another, the fibre would be broken. The importance of treating the fibre in the right way to begin with might be understood from the fact that Heilmann's combing machine, which combed the fibres and laid them parallel without breaking them, had in the course of only five or six years become extensively applied to cotton, wool, and flax; and in the case of cotton a better yarn was produced by the use of this machine out of cotton that was 6*d.* or 7*d.* per lb. cheaper than that required under the old method of carding. A series of these machines also selected the fibres according to their length, and he had known as many as fourteen different lengths of fibres got out of one sample of material; of these the longest could then be taken for the best class of work, and the shorter lengths for inferior work. If care were taken that the fibres thus combed and laid parallel should not be broken in the after treatment of the material, so as to maintain their length and uniformity, the yarns spun from such a sliver would be five or six times as strong as under the old mode of preparing the fibres.

Mr. E. A. COWPER remarked that at Portsmouth dockyard which he had lately visited scarcely any machinery was used for rope making, steam power being employed only to turn the spindles of the ordinary hand machines. There appeared to be a strong prejudice against machine-made hemp rope, which was said to be deficient in strength. He was glad to learn however that at Chatham attention was now being paid to the subject, for he was satisfied that hemp ropes could be thoroughly well made by machinery, and that more strength could be got with hemp rope properly made by machinery than with hand-made rope of the same size.

The CHAIRMAN enquired what was the reason why Capt. Huddart's machinery was discarded at the dockyard, if other manufacturers had found the machine-made ropes could be made so superior to hand work ; and whether the machinery was still in use at any other of the dockyards.

Mr. E. A. COWPER replied that Capt. Huddart's machinery was used for upwards of forty years at the Deptford dockyard, but at the end of that time the government pulled it down and it was bought by Huddart's firm, and it was not now used in any of the government dockyards : but he had not been able to ascertain the reason why it was given up there, when the use of machinery had been found so advantageous elsewhere.

Mr. P. HAGGIE said that some years ago his works were visited by some government officials for the purpose of testing some government hand-made ropes with his machinery ; and he had since learnt that they found the manufacture of the hemp ropes as carried on by machinery at the works was much superior to the old plan of hand work in the government yards ; but there the matter was allowed to drop, and the question had been shelved ever since. With regard to the plan of repeated rolling with a succession of rollers in preparing the hemp for spinning, he believed that method would not apply to long fibres such as those of hemp, the ordinary length of which was from 5 to 6 feet, and therefore there was no other way of dealing with the hemp but that which they adopted of getting the fibres as nearly straight as possible, with the least possible drawing, so as to get the greatest amount of strength out of the hemp.

Mr. E. A. COWPER observed that in passing the hemp through the drawing rollers the distance between the successive pairs of rollers must of course be arranged according to the length of the fibres, in order that the fibres might not be broken in the machine : and the same precaution had to be observed, whatever was the material undergoing preparation.

Mr. F. JENKIN remarked that in the new horizontal wire rope machine now described the wire appeared to undergo a considerable amount of bending in its course from the bobbin to the laying plate, each wire being bent on all sides successively during each revolution of

the machine in passing through the hollow nipple in the centre of the revolving disc, becoming thus crimped into a wavy form with a length of wave corresponding to the length of lay of the strand. This might not be of any importance in the case of small wires, but in large wires he thought it would be a serious defect to bend the wire in this manner; and he enquired whether any of the machines had been applied to laying large wire into strands.

Mr. A. SMITH explained that the bending of the wire previous to its arrival at the point of laying was not peculiar to the new machine, but was common to the previous vertical machines also: it was only more apparent in the horizontal machine, because the length of the machine was there so great that it was desirable to shorten it as much as practicable by increasing the angle of bending. But so long as the bending of the wire between the bobbin and the point of laying was less than the bending it received in being laid into the strand, no harm was done, whether the wire were thick or thin: had it been of importance to avoid bending the wire more than necessary, the machine might have been lengthened to the required extent for the purpose. The new machine had been applied to large wire as thick as No. 4 wire-gauge or 0.240 inch thick, without any injury to the wire; and it had been adopted and successfully employed by Messrs. Glass Elliot and Co., for laying on the covering wires for protecting the shore ends of telegraph cables.

Mr. T. SNOWDON asked whether the wire was bent so much as to cause it to scale.

Mr. A. SMITH replied that it was never bent to such an extent as to throw off a scale.

Mr. J. FLETCHER remarked that no harm could be done to the wire if the bending in the machine were less than that which it had upon the bobbin.

Mr. P. HAGGIE observed that the strength of steel wire had been stated in the paper to be twice that of the best charcoal iron wire, but his own experience was that the best steel wire was only 50 per cent. stronger than charcoal iron wire, while the common run of steel wire was not more than 10 per cent. stronger than iron, and some steel wire was not even equal in strength to iron. It was also a question

of great importance how to prevent steel wire as well as iron wire from becoming brittle in work: the wire seemed to change its character and become crystallised by the friction the rope was exposed to in passing over a series of pulleys, and in a few months' time the rope became quite brittle. The process of crystallisation was slower in iron wire than in such steel wire as had hitherto been made for the purpose of wire ropes.

The CHAIRMAN enquired what had been found to be the actual strength of ropes made of charcoal iron wire.

Mr. P. HAGGIE replied that he had lately tested an iron wire rope of about $1\frac{1}{10}$ inch diameter, which had been in use three months, and it bore $18\frac{1}{2}$ tons before breaking; it was a "formed" rope of six strands, each strand being "formed" of 19 wires twisted together, of No. 16 wire-gauge or 0.065 inch thickness, so that the whole rope contained 114 wires or 0.378 square inch section of iron, giving a breaking strength of 50 tons per square inch. This rope had been damaged by an accident, and was tested for the purpose of ascertaining its strength in the uninjured part.

Mr. SHELLEY asked what size of hemp rope would be required to bear the same weight as the wire rope, and what would be the respective weights of the two ropes.

Mr. P. HAGGIE replied that an 8 inch hemp rope would be required to bear the same load of $18\frac{1}{2}$ tons before breaking, that is a hemp rope of 8 inches circumference or rather more than $2\frac{1}{2}$ inches diameter, or else a flat hemp rope $4\frac{1}{2}$ inches broad composed of four smaller ropes: the last hemp rope that he tested of about that size, $8\frac{1}{2}$ inches circumference, broke at 28 tons, but that was an extreme case. The weight of the hemp rope was about $1\frac{1}{2}$ times that of the wire rope of the same total strength; for the 8 inch hemp rope weighed 16 lbs. per fathom, while the wire rope was 10 lbs. per fathom.

Mr. A. SMITH said that as regarded the relative strength of steel and iron wire the statement in the paper was founded upon a number of experiments that he had witnessed, from which it appeared that 500 lbs. was a very fair breaking test for charcoal iron wire of No. 14 wire-gauge or 0.085 inch thickness, amounting to 40 tons per square inch section of metal; while he had seen steel wires of the same gauge,

of a superior manufacture, bear 1000 and even 1100 lbs., or 80 to 90 tons per square inch. He thought it was generally admitted that ordinary steel wire made for wire ropes would bear nearly double the strain of iron wire of the same gauge, the generally received proportion being 7 to 4. Fowler's steam plough afforded a good instance in which fine steel wire ropes were used with advantage, from their superior strength and lightness as compared with iron wire ropes: and he had also heard of a valuable application of steel wire rope in France for transmitting power to half a mile distance; in this case the ropes used were very light, only about 5-16ths or 3-8ths inch diameter, and were driven at a very high velocity.

Mr. E. A. COWPER observed that some experiments which he had made on the strength of Webster and Horsfall's hard steel music wire gave the ordinary breaking strength at about 85 tons per square inch. In one case of very hard wire the breaking weight was found to be as high as 130 tons per square inch, but this wire was rather too hard for use.

Mr. P. HAGGIE said the highest result he had obtained with steel wire rope was in a rope of $3\frac{1}{2}$ inches girth which he had just tested, made of the best quality of wire, which broke at $35\frac{1}{2}$ tons; while an iron wire rope of the same size would break at about $22\frac{1}{2}$ tons. But this seemed an exceptional case, for in other steel wire ropes which he had tried of the same size the highest breaking strain was only $22\frac{1}{2}$ tons: and he had found a single bundle of steel wire contain so many varieties of temper that the objections against the use of steel wire ropes appeared more serious than those which had been urged against machine-made hemp ropes from irregularity in the spinning of the yarns.

The CHAIRMAN enquired what would be the strength of a hemp rope of the same size, and what was the relative durability and cost of hemp and wire ropes of the same strength.

Mr. P. HAGGIE replied that a hemp rope of $3\frac{1}{2}$ inches girth would not bear more than about $3\frac{1}{2}$ or 4 tons. But in comparing hemp and wire ropes of the same strength he believed that if the same attention were bestowed upon the hemp rope as upon a wire rope the hemp rope would be found more economical in durability as well as in first cost,

provided the depth of the pit were not extreme. Beyond a certain limit indeed a hemp rope used for winding in a pit would kill itself; that is the great weight of the rope itself hanging down the pit and the consequent continued stretching every time it was lowered would eventually cause it to become almost rotten, and it would then give way.

The CHAIRMAN hoped Mr. Haggie would give the results of his experiments on the strength of hemp and wire ropes in the form of a paper at a future meeting of the Institution. He proposed a vote of thanks, which was passed, to Mr. Shelley and also to Mr. Smith, for the information communicated in the paper that had been read, and the numerous interesting models and specimens by which it was illustrated.

The Meeting was then adjourned to the following day. In the afternoon the Members visited the Government Small Arms Factory at Enfield.

The Adjourned MEETING of the Members was held in the Lecture Theatre of the Royal Institution, Albemarle Street, London, on Thursday, 3rd July, 1862; Sir WILLIAM G. ARMSTRONG, President, in the Chair.

The following paper, communicated through Mr. Charles P. B. Shelley of London, was read :—

ON THE CONSTRUCTION OF SUBMARINE TELEGRAPH CABLES.

BY MR. FLEEMING JENKIN, OF LONDON.

The Submarine Telegraph Cables that are now in successful operation are nearly all of one general construction; and this description of cable will be first referred to in the present paper. The only essential parts of a submarine telegraph cable are: first, a conductor along which the electricity may flow from one station to another; and second, an insulator surrounding the conductor and separating it entirely from the sea. In the common cable a wire or strand of copper forms the conductor, which is covered and insulated by gutta-percha. This core of gutta-percha covered wire is served with tarred yarn, round which a greater or less number of iron wires are laid spirally, to afford longitudinal strength and lateral protection.

A cable of this class is shown in Figs. 1, 2, and 3, Plate 63, which represent the Malta and Alexandria telegraph cable, laid in 1861, drawn double full size: the copper conducting core A, Fig. 3, is shown black in section, and is surrounded by three coatings of the insulating gutta-percha B. Copper is used for the conductor because it resists the passage of electricity less than any other available metal, whereby a greater number of words per minute can in a submarine cable be sent through a copper wire than through an iron or steel conducting wire of the same dimensions and placed in the same circumstances. Different specimens of copper vary greatly in their resistance; some commercial copper has in this respect only 14 per cent. of the value of chemically pure copper, or is 86 per cent. inferior to the latter, which however cannot be practically obtained in commerce. The course followed by the principal manufacturers of telegraph cables is to select by an electrical test the wire best suited to their purpose; and this wire is about 20 per cent. inferior in conducting power to pure copper.

A solid wire would be preferable electrically to a strand, for the same reason that copper of small electrical resistance is preferable to copper of high resistance, the object being in all cases to obtain the greatest conducting power within a given circumference. The interstices in the strand diminish the conducting power for a given size, and the gutta-percha sheath must be of proportionately larger diameter to give the same speed of transmission and the same insulation as when a solid core of equal weight is used. When large conductors are required however a solid wire is not found flexible enough; and moreover a single copper wire is found liable to break inside the gutta-percha, without any external symptom of injury being seen: for these reasons a strand is almost universally adopted for large cores.

In the cables first made, the interstices between the wires of the strand were left vacant; but it was found that under continued pressure the water invariably penetrated into these vacant spaces and percolated along them. This was thought dangerous for various reasons, and therefore the Gutta-Percha Company now lay up their strand in an insulating compound called "Chatterton's compound," consisting of gutta-percha and resinous substances, which so completely fills the spaces that a pressure of 600 lbs. per square inch cannot force a single drop of water six inches along the finished core: other makers have adopted the same plan. The cables shown in Figs. 1, 2, and 12, Plates 63 and 66, have this compound between the wires of the strand; while the Red Sea cable, Fig. 7, Plate 64, and several earlier cables are without it.

In reference to the electrical conditions determining the best dimensions of the conductor and its insulator, it is sufficient here to observe, first, that for every given ratio between the cost of the materials of the insulator and of the conductor there exists a corresponding ratio between the diameters of the conductor and insulator which will give the maximum efficiency at a minimum cost; and practically the thickness of the gutta-percha is almost always in excess of this theoretical thickness. Secondly, if a constant ratio is maintained between the diameters of the conductor and insulator, the number of words per minute which can be sent through a given length

of core is simply proportional to the quantity of the materials used ; so that a core to transmit twenty words per minute will weigh four times as much and cost about four times as much as a core to transmit only five words per minute.

The manufacture of the copper conducting strand is extremely simple. Owing to the soft nature of the metal, it seems to be of little importance whether the wire is twisted in making the strand or not ; although in the outer iron sheathing of the cable it is of special importance for the wires to be "laid" without twist. In the diagram, Fig. 18, Plate 67, is shown a simple form of strand machine, and the twist of the wires is shown by the direction of the arrows upon the four bobbins. A friction break restrains the movement of each bobbin, and is adjusted by hand until the spinner feels that the tension of each wire is equal. The drums of the bobbins are made large in proportion to their total diameter when full of wire, so that the leverage of the break does not vary rapidly during the unwinding of the wire. It is important that every wire of the strand should be put in with a constant and equal strain, otherwise one wire will sometimes ruck up during the subsequent covering process, and knuckle through the insulating covering. Each length of wire is soldered to the next length, so that there may be no loose ends which might come through the gutta-percha. Where one piece of strand is joined to the next, a scarf joint is made, lapped round with binding wire and neatly soldered.

In covering the strand the gutta-percha is applied in a plastic state, in successive coatings over the strand, which is for this purpose drawn through a series of dies, each one in succession larger than the preceding. Between the several layers of gutta-percha a coating of Chatterton's compound is laid on in the Malta and Alexandria and other cables, as indicated by the strong black lines in Figs. 1, 2, 7, 8, 9, 10, and 12, Plates 63 to 66 ; but the Atlantic cable, Fig. 6, and the other cables shown in Figs. 4, 5, 11, and 13, are represented with a solid covering of gutta-percha, because no Chatterton's compound was here used between the several layers of gutta-percha. The Red Sea cable, Fig. 7, Plate 64, and several earlier cables had the

compound between the coats of gutta-percha, though not between the wires of the copper strand ; the latest cables have both.

When india-rubber is employed as the covering it is applied in strips wound spirally round the strand in most cases ; but it is put on longitudinally in the plan invented by Mr. Siemens, and described at a former meeting (see Proceedings Inst. M. E., 1860, page 137). Solvents were at one time used to joint the strips of india-rubber, but they are now generally cemented into a solid mass by heat applied in various ways. But in Mr. Siemens' plan the simple contact under pressure of freshly cut surfaces of india-rubber is said to be sufficient to join the longitudinal strips without the use of extra heat or solvents.

The question of the relative merits of the two materials, gutta-percha and india-rubber, for the covering of telegraph cables, is one of much practical interest. Gutta-percha sometimes contains impurities, and air bubbles were at one time not uncommon in the covering with that material ; these air bubbles and impurities become serious faults under the action of powerful electric currents. Gutta-percha becomes plastic at about 100° Fahr., and the copper wire sometimes forces its way through the insulating sheath when the gutta-percha is accidentally softened by heat ; moreover joints unskilfully made are liable to decay in time. On the other hand the merits of gutta-percha are very great. Not a single yard of submerged gutta-percha has ever decayed ; and the importance of this fact after the experience of many years on some thousands of miles of wire can hardly be over-estimated. No gutta-percha cable has ever failed except from local imperfection or accidental injury ; two causes of failure to which all known materials must be subject. The insulating properties of gutta-percha as now supplied are extremely good. No known material insulates perfectly ; but if 2000 miles of the same gutta-percha covered core that was supplied for the Malta and Alexandria cable, perhaps the best yet constructed, were laid say across the Atlantic ocean, and were maintained at the very improbable and disadvantageous temperature of 75° Fahr., the current received through that cable would amount to 97½ per cent. of the current

which would be received through a cable with absolutely perfect insulation. Roughly speaking it may be said therefore that the insulation of that cable was for a length of 2000 miles within $2\frac{1}{4}$ per cent. of perfection. Further improvements in insulation may be effected, but they are really of no practical importance, since they can only affect the very trifling difference between absolute perfection and the high degree of insulation already attained: and in the author's opinion no increased cost would be justified for obtaining any further increase in the insulation of the wire. Sound gutta-percha covered wire may therefore be considered practically perfect in insulation, and well made joints are as good as any other part of the core.

It may be remarked here that the word "insulation" has frequently been used in a double sense: first, as implying freedom from mechanical defect or impurity; and secondly, as implying electrical resistance. Consequently some statements that are true when the word is used in one sense have been incorrectly applied with the word in the other sense, causing some confusion in the comparisons of gutta-percha and india-rubber. Thus the circumstance that india-rubber is a better insulator in consequence of having a higher electrical resistance than gutta-percha has in mistake been incorrectly taken to mean that india-rubber is the better material for covering telegraph cables; whereas the words "better insulator" imply properly in this case a superiority in the one respect of non-conducting power alone, and not a general superiority in all respects.

The defects of india-rubber differ with different makes: some kinds are liable to turn into a treacly substance on the outer surface and next to the copper; others are liable to little cracks or fissures which appear only after the cable has been manufactured for some time; and other kinds turn slimy in water, arising it is said from a considerable absorption of water. The cause of these defects does not seem well understood, and various reasons have been assigned by different makers: such as injury of the india-rubber from heat applied to make the joint, or injury from the strain put on the india-rubber strips as they are wound on; defective structure arising in the preliminary mastication of the material in its preparation; or some

injurious effect of the contact with the copper. Exposure to light and air is also generally allowed to be injurious; but in the author's opinion the real causes of failure in india-rubber covered cables must be considered not yet satisfactorily ascertained. One defect is common to all forms of india-rubber covering, namely the necessary difficulty of making the continuous joint which is required along the whole wire; and another defect common to all forms of non-vulcanised india-rubber is the liability to injury from grease or oil. The latter danger is of the most insidious kind, for the injury is not immediately apparent, but requires a long time for its full development.

The merits of india-rubber however are not to be passed over lightly, and if they do not justify its general adoption as yet, they certainly entitle it to all the attention it has received for the manufacture of telegraph cables. When properly prepared it is an excellent insulator in the limited electrical sense of the word; whether better or worse than the present gutta-percha does not much matter, as has been shown above. It maintains its insulation better at high temperatures than gutta-percha, and will bear a higher temperature without permanent injury; it has also been thought by some less liable to mechanical injury than gutta-percha. But by far the most important point claimed in its favour is that a greater number of words per minute can be transmitted through a wire covered with india-rubber than through the same wire covered with the same quantity of gutta-percha of the usual quality. There is reason to believe that in this respect india-rubber is twice as good as any gutta-percha hitherto practically supplied for cables; but a few specimens of gutta-percha have certainly been manufactured which even in this respect are on a par with the best makes of india-rubber. An endeavour has been made by Mr. Siemens to obviate the defects and retain some of the advantages of india-rubber by protecting it inside with Chatterton's compound and outside with gutta-percha. The core of Mr. Siemens' cable, shown in Fig. 15, Plate 67, is covered in this manner, E being the india-rubber covering, with a coating of gutta-percha B outside, and a layer of Chatterton's compound F inside, covering the wire strand A: in this case the copper strand is made up more nearly to a circular form by the

addition of six small wires placed in the grooves between the six external wires of the strand, as shown in the enlarged section of the core, Fig. 17, drawn six times full size.

The main practical question still is, which material offers the best chance of permanency; and at present in the writer's opinion the answer must be in favour of gutta-percha, which is supported by the fact that the old telegraph companies continue to employ gutta-percha for their new cables.

The serving with hemp or jute yarns C, Fig. 3, Plate 63, as practised at present, is done by machines similar to those strand machines which put a twist into the wire or yarn; and advantage is taken of the flexibility of the yarn to place the bobbins in any convenient position. A large number of yarns are used, put on with a long twist or pitch, in order to avoid any chance of bending or twisting the core if one yarn breaks or is not so taut as the others. The serving merits more attention in the author's opinion than it has received, and he considers that many machines for manufacturing telegraph cables still put too much strain upon the core, especially when it is small and weak; and that the hemp might be applied so as to protect and strengthen the core much more effectually than is now the case, and thus form a much better preparation than is now afforded for the final process of sheathing with iron wires. The usual cores, both before and after they are served with the yarn, are very weak and liable to be stretched if any hitch occurs in the feed of the machines; and the author believes that several mishaps might be traced to this cause, and that the construction of a thoroughly good serving machine is a desideratum of much importance. The yarn protected by wires remains sound under water for a long time.

The final process of sheathing the cable with iron wire D, Fig. 3, Plate 63, is similar to that of making wire rope; and the machines used for the one purpose answer for the other, with the simple addition of a guide for the central soft served core. All the machines used "lay" the wire without twisting it, the same as in the manufacture of wire ropes.

Only the commonest form of submarine cable, Fig. 1, Plate 63, has hitherto been described, consisting of one insulated conductor served with hemp and protected by iron wires laid round it. A description will now be given of some of the other forms that have been used or proposed.

Instead of one gutta-percha covered core, several separately insulated wires are frequently included in one sheath, as shown in Fig. 4, Plate 64, which represents a cable of this class laid in 1854 between Spezzia and Corsica. This cable and all the subsequent ones are shown double full size in the engravings. This cable has six insulated conductors, which are all now in working order; and the cable has not cost anything for repairs since first laid, and is still in constant work. The several insulated wires in this and similar cables are coated with gutta-percha, and then laid up with hemp worming into a strand by laying machines similar in general arrangement to those for sheathing. The gutta-percha covered wire is of course not twisted, but the hemp generally is. The cables across the English Channel are generally of this class.

In the Atlantic telegraph cable, shown in Fig. 6, Plate 64, laid in 1857, the simple iron wires of the sheath were replaced by small strands, made each of seven wires of 0.028 inch diameter; but these were found objectionable on account of their rapid corrosion.

Strands formed of thick wire are however frequently used to cover heavy shore ends of telegraph cables, and are almost necessary in the largest cables for giving sufficient flexibility. In Figs. 9 and 10, Plate 65, is represented the Holland cable about to be laid, the shore end of which, Fig. 10, weighs 19.6 tons per nautical mile; the external protecting wire is here 0.220 inch diameter in the strands covering the shore end, while the single wires covering the main cable are 0.375 inch diameter, Fig. 9; but in the process of manufacture the cable was wound round a 7 feet drum without difficulty.

In the Toulon and Algiers cable, Fig. 8, Plate 64, laid in 1860, the iron wires of the sheath were replaced by steel wires, 0.085 inch diameter, each covered by a tarred hempen strand. This form though convenient in many ways has been abandoned, because the marine insects eat away the hemp with great rapidity, leaving a mere bundle

of loose wires. Simple hempen coverings have also been proposed, and in a few instances unsuccessfully tried.

A single copper wire however, 0·065 inch diameter, merely covered with gutta-percha, Fig. 5, Plate 64, was laid successfully between Varna and Balaclava in 1855, during the Crimean war, a distance of 300 miles, and worked for about nine months.

In a construction of telegraph cable proposed by Mr. Allan, no outer covering of wires is used, but the gutta-percha covered wire is strengthened by a layer of small steel wires round the copper conductor, as shown in Figs. 13 and 14, Plate 66. It is doubtful whether this plan is preferable to a simple copper strand covered with gutta-percha; though superior mechanically, it is far inferior electrically.

The rapid corrosion of the outer wires in some situations when submerged is perhaps the chief defect of the common type of submarine cable. To prevent this corrosion the Isle of Man cable, shown in Fig. 11, Plate 66, and the Wexford cable had a bituminous compound applied over the iron wires on Mr. Latimer Clark's plan. The Isle of Man cable was passed through the hot melted compound, and was considered to have been injured in some places by having been accidentally delayed in its passage through the hot material. The Wexford cable was not passed through the melted mass, but had the compound thrown over it or basted on, and by this simple contrivance a very serious danger was avoided. This plan of preventing the decay of the iron wires is fast coming into favour.

As a protection against rust it has also been proposed to cover each of the outer wires separately with gutta-percha. A cable of this make, shown in Fig. 12, Plate 66, with strands composed of three iron wires instead of single wires in the sheath, was suggested by Mr. Chatterton for the new Atlantic line, and except on the score of cost seems well adapted for the purpose. It has also been proposed to protect the iron wires by vulcanite, applied either as a general coating or to each wire separately.

In a plan introduced by Mr. Siemens, instead of protecting the iron wires they are omitted altogether, and another material considered more durable is substituted. This construction of cable is shown in

Figs. 15, 16, and 17, Plate 67. The core is surrounded with two layers of hempen strands CC, Fig. 15, laid on under considerable tension. Three or more strips of copper or brass GG, about 0.01 inch thick, are then bound round these strands while they are still stretched by the tension; and this copper or brass sheathing grips the hempen cords tightly, so that they cannot contract longitudinally after leaving the machine. By this construction a cable is obtained which is extremely light and strong; thus a cable $\frac{3}{8}$ inch diameter bears a strain of 15 cwts. before breaking, and stretches only 0.8 per cent. of its length under a load of half the breaking strain. Mr. Siemens is of opinion that from the experience obtained from the sheathing of ships' bottoms, the copper or brass strips outside this cable will be far more durable than the iron wires of the usual cable; experience however with telegraph cables can alone finally decide this point, which admits of much discussion.

The machine used for sheathing the cable with the metal strips is shown in Figs. 19 and 20, Plate 68. Two serving machines are placed one behind the other, and are driven in opposite directions, laying on two distinct hemp coverings. The number of bobbins or the size of the strand in the two machines is so adjusted that each covering although of different diameter may have the same lay or pitch of the spiral. Each hemp strand passes round a V pulley between the bobbin and the laying plate, and an adjustable break is applied to each of these pulleys to strain or stretch the strands. A cable of $\frac{3}{8}$ inch finished diameter has two layers of 16 hempen strands each, and each strand is laid on under a strain of 8 lbs. In front of the two serving machines and driven by a separate band stands the sheathing machine, Fig. 19. The copper or brass strips GG are wound on bobbins H, as in the usual serving machines; and are drawn off from the bobbins to certain guides of peculiar form close to the served core. These guides lead the several strips so that each strip laps over the preceding one by about one third of its breadth. The core is supported and compressed by the tightening nozzle II up to the very spot at which the metal strips are laid on. The nozzle I is made up of segments contracted by an adjusting screwed nut, a transverse section of which is shown one quarter full size in Fig. 21. The strips laid on lapping over one

another would form a cone instead of a cylinder, if it were not for a series of rollers JJ, between which the metal sheathed cable is immediately passed. These rollers forcibly compress the metal sheathing into a cylindrical shape; and a simple adjustment regulates the pressure exerted by all the rollers, as shown in the end elevation, Fig. 20, by means of circular inclined surfaces K pressing upon the ends of the slides that carry the rollers, which are all adjusted simultaneously by the hand wheel L. The result of the manufacture is certainly a cable very beautiful in appearance; its practical value can only be decided by experience, but in the author's opinion it is superior to any of the very light cables hitherto proposed.

The copper or brass sheathing affords lateral protection to the core; the longitudinal strength of the cable is amply sufficient both for the necessary strain during submergence, and to provide against accidental injury; and insects will not lodge in the hemp so long as the metal sheathing remains intact. There may be some ground for apprehension, in the author's opinion, as to the durability of the light copper or brass sheathing; but this must necessarily be left to be decided by further experience on a large scale.

In reference to the defects of the usual iron wire sheathing as shown in the drawings, it may be observed that some misconceptions have existed upon the subject. It seems to be generally supposed that wires laid on spirally round a soft core must, as soon as any strain comes upon them, stretch somewhat in the way that a spiral spring does; and many attempts have been made to obviate this supposed defect: but on actual trial no defect is observed. The single open helix of a spring stretches by diminishing the diameter of the coil; but when a number of wires are laid up touching one another, so as to form a solid ring or cylinder round a centre, as in a telegraph cable, the diameter of the ring cannot diminish, even though the centre of the cable is soft; and consequently the only stretching that occurs is due to the elongation of the iron itself, added to a very small constant due to the more perfect closing of the wires one against another. The following experiment on the stretching of telegraph cables is taken at random from a very large number made by the Board of

Trade Committee on submarine telegraph cables, all confirmatory of this view. The total section of iron in the Red Sea cable which was experimented upon, shown in Fig. 7, Plate 64, is about 1-10th square inch; and one sample 100 inches long elongated 0.56 per cent. with 75 cwts. strain; and it broke with $77\frac{1}{2}$ cwts., or about 39 tons per square inch strain upon the iron wire. Other samples of the same cable elongated about 1 per cent. with 85 cwts. Then single iron wires of about the same size as those in the cable, 0.085 inch diameter, were found to stretch from 0.46 to 0.72 per cent. before breaking, and bore about 4.4 cwts. each, or 39 tons per square inch. It appears therefore from experiment that there is hardly any difference in elongation between a solid rod and a well laid up cable; and in strength no difference whatever between the cable and the wire composing it. The core does not, as at present made, add sensibly to the strength of the cable; for its resistance to the extension of say one per cent., at which the cable breaks, is insensible compared with that of the iron wire sheathing.

The twist put into a cable by the usual mode of coiling it when laid in a mass, as in the hold of a vessel, has also sometimes been misunderstood: a twist is no doubt put into the cable by the process of coiling, but this twist is as certainly taken out again when the cable is uncoiled, and is therefore of no importance.

The only inconvenience attending the spiral lay of the cable sheathing, in the author's opinion, is first apparent when the cable is being paid out, without sufficient strain upon it to lay it taut along the bottom. Then as the slack accumulates the cable becomes virtually free at the bottom, while the parts near the surface of the sea have considerable weight to bear; and the cable therefore untwists and throws itself over into a bight. The number of turns taken out of the cable, and of bights put into it along the bottom, depends simply on the amount of slack paid out. When the cable is again picked up, these bights draw tight into kinks, to the injury of the recovered cable; and this is the only practical inconvenience attending the usual spun cables. The amount of elongation consequent on the untwisting is quite insignificant; and, except for these kinks, telegraph cable recovered after three years from 1500 fathoms depth has been found just as good as when it was laid down.

The common iron covered cable can be easily laid safely in depths not exceeding 1000 fathoms ; but beyond that depth steel wire should be used for the sheathing, or the specific gravity of the cable diminished. Exposed hemp is not admissible, owing to the marine insects already mentioned, which are found at all depths.

The general result of all the facts that have been ascertained with respect to submarine telegraph cables may be said to be that all the heavy cables have succeeded, and all the light cables failed ; and the present tendency is certainly to lay heavier and heavier cables, protected by some composition against rust. It must be remembered however that all the heavy cables except that between Spezzia and Corsica have been laid in shallow water, whereas the small cables have been used in deep water : but the facts by no means prove that some new form of light cable may not ultimately be successful in deep water. The shore end of the new cable about to be laid between Holland and England, shown in Fig. 10, Plate 65, is a fine example of the heavy class of cables, weighing 19·6 tons per nautical mile : the iron wire sheathing is here made double, the core being covered with fifteen wires 0·220 inch diameter, which are served with hemp, and then covered with twelve strands of three 0·220 inch wires each : it is further to be covered with pitch and hemp.

The following Table I (appended) gives the particulars in a tabular form of the actual constructions of cables that have been described and shown in the engravings, together with the weight per nautical mile of each form of cable. Table II gives a list of the principal submarine telegraph cables now in working order ; showing the length of each cable, the maximum depth of water in which it is laid, and the length of time it has now been working.

In conclusion the author would remark that he has not attempted to produce a complete account of the various forms of submarine telegraph cables, nor to enter fully into the merits or demerits even of the one most usual type of cable ; he has simply endeavoured to draw attention to those points in the different constructions which affect their practical value and durability, so as to bring the subject fairly before the meeting for discussion.

TABLE I.
Construction and Weight of different Submarine Telegraph Cables.

Date when laid.	Plates 63 to 66.	Locality.	Core.						Iron Sheathing.			Weight per nautical mile of Cable complete.	Remarks.
	Fig.		Number of separate insulated Conductors.	Number of Wires in each conductor.	Diameter of each Wire.	Diameter of whole Conductor.	Weight of Copper in each conductor per nautical mile.	External diameter of insulating Covering of conductor.	Number of Wires.	Diameter of each Wire.	External diameter of iron Sheathing.	Tons.	
1854	4	Spezzia and Corsica ...	6	1	Inch. 0·065	Inch. 0·065	Lbs. 70	Inch. 0·28	12	Inch. 0·300	Inch. 1·50	8·50	Deep water; in good working order; has cost nothing for repairs.
1855	5	Varna and Balaklava ...	1	1	0·065	0·065	74	0·30	—	—	—	0·11	No sheathing; lasted nine months.
1857	6	Atlantic, old... ..	1	7	0·028	0·085	105	0·38	126	0·028	0·62	1·15	Sheathing 18 strands of 7 wires each.
1859	11	Iale of Man	1	1	0·065	0·065	72*	0·34	10	0·190	0·80	2·88	Sheathing covered with asphalt and hemp yarn. *(Weight of conductor approximate.)
1859	7	Red Sea and India ...	1	7	0·038	0·105	180	0·34	18	0·077	0·56	1·05	
1860	8	Toulon and Algiers ...	1	7	0·028	0·085	105	0·34	10	0·085	0·80	1·33	Sheathing, steel wires, each covered separately with tarred hemp.
1861	1	Malta and Alexandria, { main cable ... }	1	7	0·060	0·165	400	0·46	18	0·120	0·85	2·13	Length 1330 nautical miles successfully laid, chiefly in shallow water; has cost nothing for repairs.
"	2	Ditto, shore end	1	7	0·060	0·165	400	0·46	12	0·260	1·28	6·90	
1862	9	England and Holland, { main cable ... }	4	1	0·085	0·085	128	0·34	10	0·375	1·58	10·40	
"	10	Ditto, shore end	4	1	0·085	0·085	128	0·34	{15·0·220} {36·0·220}	{2·00 {2·00		19·60	Double sheathing; 15 wires covered with 12 strands of 3 wires each.

TABLE II.

Principal Submarine Telegraph Cables now in working order.

Date when laid.	Locality.	Conductors.		Sheathing.		Length of cable in nautical miles.	Depth of water in fathoms.	Length of time working.
		Number.	Diam.	No. of wires.	Diam. of wires.			
			Inch.		Inch.	Naut. miles.	Fms.	Years.
1851	Dover and Calais	4 wires	0·065	10	0·300	24	—	11
1853	Dover and Ostend... ..	6 ...	0·065	12	0·280	70	—	9
1853	Portpatrick and } Donaghadee	6 ...	0·065	12	0·280	22	—	9
1853	England and Holland ...	1 ...	0·065	10*	0·165	105	30	9
1854	Portpatrick and } Whitehead	6 ...	0·065	12	0·280	24	—	8
1854	Spezzia and Corsica ...	6 ...	0·065	12	0·300	96	325	8
1856	Newfoundland and } Cape Breton	1 strand	0·085	12	0·150	74	360	6
1857	Norway, across Fiords...	1 ...	0·085	10	0·200	43	300	5
1857	Ceylon and India	1 ...	0·085	—	0·165	26	—	5
1858	England and Holland ...	4 wires	0·095	10	0·375	122	30	4
1858	England and Hannover	2 strands	0·065	12	0·190	244	30	4
1858	Ceylon and India	1 ...	0·085	12	0·165	26	45	4
1859	England and Denmark...	3 ...	0·065	12	0·210	320	30	3
1859	Sweden and Gotland ...	1 ...	0·085	12	0·150	56	80	3
1859	Folkstone and Boulogne	6 ...	0·085	12	0·340	21	82	3
1859	Malta and Sicily	1 ...	0·085	10	0·210	52	79	3
1859	England and Isle of Man	1 wire	0·065	10	0·190	32	30	3
1859	Tasmania, Bass' Straits	1 strand	0·065	10	0·165	210	—	2½
1860	Toulon and Algiers ...	1 ...	0·085	10†	0·085	452	1585	2
1860	Corfu and Otranto ...	1 ...	0·085	10	0·210	78	1000	2
1860	Dacca and Pegu	1 ...	0·095	18	0·085	100	—	2
1860	Barcelona and Mahon ...	1 ...	0·085	16	0·102	156	1400	2
1860	Majorca and Minorca ...	2 ...	0·065	18	0·110	30	250	2
1860	Iviza and Majorca ...	2 ...	0·065	18	0·115	64	500	2
1860	St. Antonio and Iviza ...	2 ...	0·065	18	0·115	66	450	2
1861	Toulon and Corsica ...	1 ...	0·085	10†	0·085	170	1550	1½
1861	Malta and Alexandria ...	1 ...	0·165	18	0·120	1330	420	¾

* Galvanised wires.

† Steel wires covered with hemp.

Mr. JENKIN exhibited a number of specimens of the various constructions of submarine telegraph cables described in the paper, contributed by the principal manufacturers, and specimens showing the mode of soldering the successive lengths of the copper conducting wire to one another, and of joining one length of strand to the next by a soldered scarf joint.

Mr. C. W. SIEMENS thought the subject of the mechanical construction of submarine telegraph cables was one well worthy the attention of the meeting, because it was an open question yet, and one into which mechanical considerations entered very largely. The electrical question, which had also been introduced in the paper that had been read, would perhaps hardly be suitable for discussion on the present occasion; excepting the main point of importance, whether gutta-percha or india-rubber should be used as the insulating covering for protecting the copper conducting wires. He had himself no predilection for either of these materials, but thought both of them possessed very excellent qualities as well as certain defects; it would therefore be wrong to overlook the merits of one in taking too favourable a view of the other. Gutta-percha had been used by himself for a great many years, and he appreciated its advantages and knew also many of its shortcomings, on account of which he had proposed the use of india-rubber as an inner coating under the gutta-percha, not only because of the higher insulating and lower inductive property of india-rubber, but also to a great extent because of its mechanical properties. When once properly put on, india-rubber was so mobile in its particles that it might be called semifluid; and there was no flaw in it so long as it was well protected externally. External protection was necessary in order to make india-rubber effective as an insulator, because if left to itself it would easily be cut; and, what was more important, it absorbed water to a much larger extent than gutta-percha.

The CHAIRMAN enquired whether india-rubber absorbed water in consequence of any defect in the material, or whether the absorption was independent of the quality of the india-rubber; and also whether gutta-percha absorbed much water.

Mr. C. W. SIEMENS replied that all india-rubber absorbed water to a very considerable extent, independent of the quality of the material; and gutta-percha also absorbed water, but to a less extent than india-rubber, and never sufficiently to reduce its insulating property materially. From some observations that he had made it appeared that india-rubber was also slightly dissolved by salt water, which gradually formed a slime on the surface of the india-rubber, thereby diminishing its thickness; when immersed in salt water a considerable increase of weight in the india-rubber was first observable for about 150 days, and after that a loss of weight, owing to a slight separation taking place of the slimy substance on the surface of the india-rubber. He had therefore come to the conclusion that the highest insulation could be obtained by a union of india-rubber and gutta-percha: how far either of them used alone could be considered superior to the other must be left for experience to decide; but the experience that he had had of the union of the two was very favourable.

With regard to the outer sheathing of the cable, he considered the subject was treated upon the whole with great fairness in the paper that had been read; many points had been touched upon, some of which admitted of further remarks. Thus in paying out a wire-sheathed cable of the usual construction into deep water, it frequently occurred that one wire broke in the sheathing as the cable was being taken out of the hold, and this was a source of great danger; for the one broken wire with its ends separating from the cable would form an irregular mass, which in passing over the break wheel was very apt to entangle itself there and cause a rupture of the cable. This alone he considered was a sufficient ground for endeavouring to find a sheathing that would not be liable to such accidents; and it was to avoid that liability and to prevent corrosion that he had designed the sheathing now exhibited and described in the paper, consisting of thin copper strips wound round the cable. In this construction the sheathing could not uncoil because it was double throughout along the edges of the strips, and each covering strip was gripped under the succeeding one and was always held down by it, so that even if one of the strips should get cut, or indeed if all of them were

cut at the end of the cable, they could not untwist. With regard to the durability of the external sheathing, he believed there was satisfactory reason for considering that copper, and especially copper with a small percentage of phosphorus (about $\frac{1}{4}$ per cent.), or of any of the electro-negative metals such as silver or tin, was far more durable in sea water than iron.

The CHAIRMAN observed that he had also found that copper alloyed with a little phosphorus had greater strength and tenacity than when not so alloyed.

Mr. C. W. SIEMENS said experiments had been made which proved also that the copper alloyed with phosphorus was far less oxidisable and therefore far less attacked by the salt of the sea than pure copper. Moreover the copper sheathed cable as it issued from the sheathing machine was covered with a film of tar or resinous matter, which gradually became indurated and formed a strong protection to the metal beneath; and there was also a layer of tar inside the metal sheathing, both of which coatings together with the metal sheathing would have to be oxidised completely through, before the hemp could be laid bare for the marine insects to attack, which was the real danger that would arise if the metal sheathing were gone. For these reasons he thought it was desirable to employ a copper sheathed cable and one that would not uncoil, such as the specimen now exhibited of the new construction, of which some short lengths had now been laid down for trial, and he confidently anticipated the result would be favourable.

He was glad that reference had been made in the paper to the uncoiling of a cable when laid in the sea, which was not admitted by many engineers; it was perfectly true however that when a cable covered with a sheathing wound spirally round it was lowered to a great depth, the strain produced upon it by its own weight, being greatest near the ship and diminishing to nothing at the bottom, would act very much as though the end were freely suspended: the cable would partially untwist and elongate. The consequence of the untwisting was that some sort of loops must be formed at the bottom, where the untwisting action was stopped by the cable lying on the ground; and when the cable was taken up again these loops were

pulled tight into kinks, giving rise to faults in the insulation. If both ends of a cable were held tight from untwisting and an equal strain were applied, then indeed the wires would form an arch round the cable, and the elongation produced would only a little exceed the elongation of a solid wire.

The CHAIRMAN enquired what were the principal causes of failure in submarine telegraph cables after they had once been laid, when covered with gutta-percha.

Mr. C. W. SIEMENS replied that there were many causes which had been found in practice to operate in destroying submarine cables made with gutta-percha as the insulating material. In the first place the gutta-percha covering had been imperfect when the cable was shipped for laying. Many cables, especially the earlier ones, had failed because the gutta-percha covering was not perfect, but contained mechanical defects, however good the material itself might be. Air bubbles getting into its substance, in the machine by which the layer of gutta-percha was put on the copper strand, formed cavities which under the great hydraulic pressure at the bottom of the sea would be penetrated by the water. Bad joints in the gutta-percha were another and frequent source of failure. Moreover if too great battery power were applied, the gutta-percha was quite eaten through and melted away in places where the covering happened to be thin owing to a mechanical fault or injury; and it was therefore essential to use low battery power in working cables.

Another frequent cause of failure was the outer sheathing of the cable giving way: the iron wires in some places rusted entirely away, leaving the copper wire simply covered with gutta-percha. Then if the cable had been laid a little tight, or if that part hung between rocks at the bottom of the sea, as soon as the iron covering gave way the weight of the iron sheathing upon the cable would be a great source of destruction, causing those portions where the iron had been rusted away to elongate, and a fault would be developed. This was found to be the case especially in raising a cable after it had been laid some time. In the Red Sea cable, for instance, the iron sheathing had gradually been rusted completely away in some places, and in attempting to raise it the cable broke at those places,

where the gutta-percha was pulled out and faults had developed themselves.

Another cause of failure was the gutta-percha having been melted by accidental exposure to heat. If in a tropical climate a gutta-percha covered cable were allowed to remain lying for a quarter of an hour upon deck, the gutta-percha would unquestionably be softened enough to allow the copper conductor to sink by its weight through the gutta-percha so as to touch the outer materials. Pieces of the Atlantic cable which had been fished up showed evident signs of having been heated. If a piece of iron sheathed cable previously moistened were exposed to atmospheric influence, heat developed itself, as had been the case with the Malta and Alexandria cable; and if that heat rose to about 100° Fahr., the gutta-percha would be in a semifluid condition. When the cable was laid under such circumstances, it might seem successful at first, but faults would show themselves soon afterwards.

Mr. W. SHEARS remarked that, in reference to the strengthening of copper or brass by a portion of phosphorus being combined with it, he believed phosphoretted metal had no greater durability in sea water than ordinary sheathing as applied to ships' bottoms, either the yellow metal or the copper sheathing, which lasted only a few years: and therefore, notwithstanding the ingenuity of the sheathing of copper strips in Mr. Siemens' cable, he feared it would not stand very long in sea water, probably not more than about three years, and then it would cease to be any protection whatever to the hemp underneath.

Mr. N. S. RUSSELL observed that the durability of copper depended on the quality of the metal, and it was no doubt difficult at the present time to get really good copper that would last well. The copper sheathing of the "Black Eagle" had recently been taken off at Woolwich dockyard, after having been on the ship for twenty years; and it was found to have been only worn thin gradually, but was not worn in holes in any parts, showing how well the sheathing would stand when the metal was of good quality.

Mr. E. A. COWPER said it had been stated before a committee of the House of Commons that copper sheathing as formerly made could be used for twenty-five or thirty years before requiring renewal: but ships

sheathed with modern copper often required stripping in three or four years' time. The plan of mixing phosphorus with copper he believed was a new one; it had only just been tried, so that there had not been an opportunity yet of testing the durability of the phosphoretted copper; but some experiments made with it seemed to give some hope that it would last as well as the good copper sheathing made in former years for ships' bottoms: it seemed to stand well, and did not become oxidised so much as copper not containing phosphorus.

Mr. J. SCOTT RUSSELL mentioned that some enquiries had lately been made at Chatham into the subject of copper sheathing for ships' bottoms, the practical result of which was that two sorts of copper of the same chemical quality might be of opposite characters for durability in sea water, and to such an extent that while one might be considered as lasting twenty years the other would not last as many months. He had also been informed by a manufacturer of copper that in the process of manufacture the melted copper was skimmed, by taking the "cream" off, and then the "skimmed metal" that remained in the melting pot was employed for the purpose of sheathing ships. But it was found that though this "skimmed metal" was as pure copper as the "cream," and when analysed showed the same chemical composition, yet its quality for the purpose of protecting ships was greatly inferior. It was therefore important in applying copper strips for the sheathing of telegraph cables to learn what sort of copper it was that would last. The durability of the metal was also affected by the degree of friction it was exposed to by motion of the water on its surface; and perhaps the sheathing of telegraph cables, being free from currents in the water, might prove more durable than the sheathing of a ship's bottom. When a ship was laid up in dock, its copper sheathing could scarcely be kept clean; but when in motion it was kept clean by the friction of the water, and the wear of the sheathing consisted in the continual abrasion of its skin by motion through the water. Hence in vessels built with the old fashioned bluff bows, the sheathing had to be put on very thick at the bows, where there was the greatest resistance, to allow for the extra wear at that part in consequence; while in the new fashioned bow, where the resistance was uniform over the entire surface, the copper sheathing wore out more slowly at that part.

Mr. G. A. EVERITT could confirm the statement that had been made as to the practice of skimming copper in the process of melting it: the "cream" skimmed off formed what was known as best selected copper, while the "skimmed metal" left behind formed cake copper, which was the description used for copper sheathing, and was the basis of the yellow metal used for sheathing during the last few years. It was therefore readily seen that the present copper sheathing made from cake copper would be much inferior in quality to what it was ten years ago, before the practice of skimming the copper had been adopted for this purpose. As regarded the statement made in the paper in reference to the conducting power of copper wire, that the purer the copper the greater was its power of conducting electricity, he enquired whether any particular makes of copper had been found superior in this respect to others: whether foreign-smelted copper, such as Australian, Russian, or Norwegian, was better than that manufactured in England.

Mr. JENKIN replied that in respect of the power of conducting electricity the Australian copper had been found to be the best.

Mr. E. A. COWPER observed that the copper ores from Cornwall had been found better for the purposes of copper sheathing than either the Australian or the Norwegian; but it was considered to be objectionable to mix many kinds together.

Mr. C. W. SIEMENS remarked that the power of copper to conduct electricity was very greatly altered by even a slight admixture of any foreign substance: about 2 per cent. of foreign matter was known to reduce the conducting power of copper 87 per cent. He had himself tried the phosphoretted copper, and found that the conducting power was reduced to about one-fifth of what it was before the phosphorus was added. These facts bore very much he considered upon the question of the durability of the copper also, because the action of sea water upon the copper was to a great extent an electric action, and might be greatly influenced by using different kinds of copper on the same vessel; it was well ascertained that one sheet of copper would wear away more rapidly on a ship's bottom than another, and good copper was known to last even from thirty to forty years. The copper however that would be best adapted for sheathing

a telegraph cable was not perhaps that which would be the best for ship sheathing ; because in the latter case the copper was not wanted so much to last for any length of time, as to poison the animals that would attach themselves to the ship's bottom, and the yellow metal sheathing had been designed with the special view of poisoning the animals and so keeping them off. If the object were merely to extend the lifetime of the copper sheathing of a ship's bottom, its durability might easily be increased by adding tin, silver, or phosphorus to it ; but then it would become more liable to foul by the attachment of marine animals. In the case of a telegraph cable however the conditions were different : durability alone was wanted, and the sheathing was not exposed to any motion in the water. He considered that though the copper sheathing might wear away in some cases in five or six years on a ship's bottom, yet in the sheathing of a cable the same metal would last three or four times as long.

Mr. J. GRANTHAM thought the outer covering of a submarine telegraph cable was practically so much the most important part of the cable that it probably required more consideration than any other point connected with the cable. The new mode of sheathing the cable with copper strips, introduced by Mr. Siemens, appeared to have much to recommend it ; for the circumstances affecting the durability of copper sheathing when applied to a ship's bottom and when applied to covering a telegraph cable differed in the important respect that the sheathing of a ship was exposed to the friction of the ship's motion through the water as well as its rolling motion, while the cable lay undisturbed at the bottom of the sea. For the sheathing of a ship it was not in general of so much consequence that the copper should be very durable ; because the ship required stripping frequently for caulking the seams, and then the copper was necessarily destroyed and replaced by new ; but in a cable the longer the copper sheathing lasted the better. The effect of the friction produced by motion through the water was clearly shown by the greater wear of the copper sheathing at a ship's bows, where the friction was the greatest. The wear indeed was the result partly of chemical and partly of mechanical action : the surface of the copper became oxidised by exposure to the sea water, and if the ship remained at rest the sheathing became covered by a deposit, which

would protect it to a great extent from the effect of the sea water ; but by the ship's motion the friction of the water continually brushed off this coating, and thus the animalculæ attaching themselves to the ship's bottom, though probably not poisoned by the copper, could not however cling to it, being thrown off from it by a sort of imperceptible scale, whereby the ship's bottom was preserved free from fouling. These facts were accordingly favourable to sheathing a cable with copper, because the copper would itself become coated in the same manner, and even covered with animalculæ ; but while remaining at rest in the water there would be no friction to disturb that coating, which would thus protect the copper from further oxidation by the sea water. There was therefore he thought every reason to suppose the sheathing by copper strips to be a thoroughly sound protection, if the cable were properly manufactured in the first instance : and he enquired whether the strips of copper could be readily obtained of sufficient length to make the manufacture of the cable simple and easy, and so as not to require too many joinings, which would involve some inconvenience.

Mr. C. W. SIEMENS replied there was no difficulty in manufacturing the copper strips long enough, and they were made in two ways : either long strips were rolled of considerable width, and then cut up into strips of the required width by being passed through a pair of cutting rollers ; or else wire was drawn of the required size and length, and was afterwards rolled flat. In both ways strips of sufficient length could be obtained, and there was no difficulty in joining the successive lengths together ; they were simply soldered together, and it was not necessary that these soldered joints should be reliable, because each strip was held firmly by the succeeding strip being pressed into it so that it could not get away. In putting on the copper strips on a cable, the sheathing machine was stopped when each strip ran out, while the next length was soldered on.

Mr. A. SMITH observed that in reference to the relative strength of steel and iron wire in the construction of telegraph cables, upon which some remarks had been made in the previous discussion upon wire ropes, he had found the statement that steel wire had double the strength of iron wire to be fully confirmed by the results of actual experiments. For an iron wire rope of $1\frac{1}{2}$ inch circumference, made

of charcoal iron galvanised, broke with a load of $2\frac{1}{2}$ tons, while a steel wire rope of the same size broke with $8\frac{3}{4}$ tons ; and an iron wire rope of 3 inches circumference broke at $9\frac{1}{2}$ tons, while a steel wire rope of the same size broke at $26\frac{1}{2}$ tons. Hence he thought a steel wire rope might safely be taken to bear double the strain of an iron wire rope.

Mr. JENKIN said a great number of experiments had been made by Mr. Siemens and Mr. Forde as to the strength of iron and steel wires in submarine telegraph cables, and a great number of single wires had been tried by them. It was found that the steel wire was twice as strong as the iron wire ; but on the other hand it was found that, though it had so much more strength when properly manufactured, it could not always be depended upon so well as the best charcoal iron wire : uniformity of strength could not be secured in steel wire, different specimens varying greatly.

Mr. W. POLE said he had lately made some experiments for Messrs. Broadwood upon the strength of pianoforte wire, which was the strongest material known ; he had tried several specimens, and was surprised to find the very great strength it possessed. Iron was spoken of as strong when it would bear a tensile strain of 30 tons per square inch, and steel when it bore 60 tons ; but the wire he tried actually bore as much as 110 and 120 tons per square inch. It was steel wire, manufactured in Germany ; and it had in the form of wire about double the strength of bar steel made of the same material, just as iron wire was generally about twice as strong as bar iron. The iron wire of which the Niagara suspension bridge was made was manufactured in Manchester, and bore a strain of about 40 tons per square inch ; and that of the Freiburg suspension bridge in Switzerland, made of charcoal iron, bore 50 tons per square inch.

Mr. J. SCOTT RUSSELL thought that time was an element which ought to be taken into consideration with respect to the strength of wire ; for those metals which bore a very high strain under experiment did not appear to be capable of standing for any great length of time under that strain.

Mr. W. POLE remarked that this was hardly the case with pianoforte wire, because that was found to stand for a long period under a very considerable strain, often not much below its breaking strain.

Mr. P. HAGGIE observed that in reference to the strength of different sorts of wire the case of pianoforte wire was different from that of a telegraph cable or a wire rope. The pianoforte wire was drawn for a particular purpose, and was made specially hard to stand a great strain; but it was deficient in the flexibility which was specially required in a rope or telegraph cable. The strength of charcoal iron wire however he considered was much more than had been stated, and the wire must have been of very inferior quality in a rope of 3 inches circumference to break with $9\frac{1}{2}$ tons load: for the ordinary test for an iron wire rope of that size was 18 tons, to be borne without breaking. He enquired what was the proportionate strength of the new cable now described, sheathed with copper strips, as compared with cables covered with wire sheathing.

Mr. C. W. SIEMENS replied that if a wire-sheathed cable were covered with strands of small wire instead of single large wires it could no doubt be made strong enough to be quite safe against any breakage taking place; in fact the former Atlantic cable had been covered in that way, but then the consequence was that it rusted away in about half the time it would have done had single wires been used for the sheathing, on account of the much larger extent of surface exposed to the action of the sea water. For the shore ends indeed of cables a very strong covering of wire strands, something like that now adopted for the England and Holland cable, was certainly the best protection. The copper sheathed cable was not proposed for laying in shallow water, but was intended only for long deep water lines where a heavy cable could not be laid. A cable sufficiently protected with a covering of iron wire would be so heavy that it would be impossible for any one vessel to lay it down across the Atlantic; it would be necessary to stop several times during the paying out to attach another length of cable, and that would be fatal to the whole operation, since the iron would be strained to the utmost safe limit in such a cable to support itself in laying it to a depth of 2000 fathoms. A copper sheathed cable of the size now exhibited, 3-8ths inch diameter, would bear about $1\frac{1}{2}$ tons load, and therefore as regarded the breaking weight it compared unfavourably with cables covered with iron wire: but taking into consideration its lower specific gravity it was a great

deal stronger than an iron sheathed cable. The copper sheathed cable could be suspended freely in the sea to a depth of six to eight miles before breaking, whereas an iron covered cable would break at three or four miles depth: and this he considered was the proper view to take of the strength of the cable in the case of deep water cables.

Mr. W. POLE enquired whether in the covering of telegraph cables vulcanised india-rubber had proved successful as the insulating material for covering the copper conducting core.

Mr. C. W. SIEMENS replied that it was only upon brass that vulcanised india-rubber would adhere firmly, and brass had not conducting power enough to be used for the core; hitherto he believed no wire had been produced of copper securely covered with brass. There were also other practical difficulties in the way, which would prevent vulcanised india-rubber from being used as a covering.

Mr. T. HAWKSLEY observed that with regard to the use of phosphorus for alloying the copper for sheathing telegraph cables, with a view to increase the durability of the metal by enabling it to resist the action of the sea water, it was a well known fact that all pure metals had strong chemical affinities, and were always desiring to combine with anything else with which it was possible for them to combine; and accordingly when metals were perfectly pure they were easily destroyed. Thus in cast iron water pipes, and also in the use of malleable iron, if the metal were pure the pipe was speedily destroyed, either by action from within or from without; in water-works this destruction was a source of great annoyance, because it was continually going on, and if the metal were tolerably pure it went on with such rapidity that the water from the pipes could not be kept uncoloured. Those metals however which were not quite pure, but contained a small quantity of sulphur, phosphorus, silica, or carbon, resisted the action of the water, whether from within or from without, much better than the pure metals, and this was the case whether the water were fresh or salt. Hence a metal of the quality of crude steel resisted corrosion far better than pure iron; and cast iron in the vitreous state, or white metal, as it came from the furnace before undergoing the process of puddling, was found to be the best sort of metal for the manufacture of water pipes, provided it was not so hard that it could

not be drilled and worked in the manner necessary for waterworks purposes. There seemed therefore good reason for believing that the durability of the copper sheathing now proposed for telegraph cables would be greatly increased by alloying the copper with phosphorus.

With regard to the transmission of an electric current through a telegraph cable, and the size of conducting wire required, he had made some experiments on the subject several years ago, and then came to the conclusion that the transmission of electricity through a solid conducting rod followed precisely the same law as the transmission of water through a hollow pipe; it required indeed a different coefficient in the case of electricity, but in all other respects the law appeared to be exactly the same. From this law, which he believed had been generally admitted in electricity as Ohm's law, it followed that any long telegraph cable would become useless unless the conducting wire were made of considerable diameter and the intensity of the battery power were kept exceedingly low. Any cables laid with small conducting wires to a distant station such as America must necessarily fail; because if a high intensity of current were employed in endeavouring to obtain great velocity there would be an explosion through the insulating covering, beginning perhaps with only a very minute perforation at first, but ultimately destroying the value of the entire cable. The actual law which he had found by experiment to obtain in regard to the size of the conducting wire was that, in order to maintain an equal velocity of the electric current through varying lengths of cable without increasing its intensity, the diameter of the conducting wire must be increased in the same proportion as the length; but when this was effected the quantity of electricity expended was as the fifth power of the square root of the diameter, being a rather higher proportion than that of the square of the diameter. Unless this proportion were observed he believed that, though it might not be impossible to transmit signals, yet they could not be transmitted with the velocity and safety necessary to make a very long submarine cable commercially successful. He considered the main object to be aimed at in laying long lines of submarine telegraphs ought to be the maintenance of the necessary velocity of the current without any detrimental increase of its intensity.

Mr. JENKIN thought that the failures of submarine telegraph cables had sometimes been considerably magnified by estimating them in an incorrect manner. If the number of miles that had been laid were simply added together, and then the number that had proved successful and unsuccessful, it certainly appeared that about half the total length laid had failed. But it must be remembered that a single fault in a cable 2000 miles long was sufficient to render the whole cable a failure, even though all the rest of it might be in perfect condition; and he therefore considered the most satisfactory way was to take the whole number of miles laid, and the total number of faults that had occurred in them, when the faults would be found to bear but a small proportion to the miles laid. Out of 28 cables that had been laid by one manufacturer since 1854, making a total length of about 3200 nautical miles, all were now at work except only two short cables; and of the rest all but three had gone on without repair from the commencement.

The causes of failure were many, but he believed that in nine cases out of ten the failure was accompanied by a break in the copper conductor. If there were merely a fault in the insulating covering of the cable, without the copper conductor being broken, messages could still be transmitted for a certain time; and he thought the failures that had occurred in the cables across the English Channel and elsewhere had been almost always accompanied by a total breakage of the conducting wire. Some failures had no doubt been caused by small faults and impurities existing in the insulating gutta-percha before the cable was laid; but he did not think that faults in the gutta-percha were ever occasioned by electrolysis, as he believed that gutta-percha in the situation in which it was placed in a telegraph cable was not capable of being decomposed by the passage of an electric current along the cable. He had tried the experiment repeatedly by putting thin films of gutta-percha of the same kind between copper and water, in the condition in which it would be in a telegraph cable, and had been unable to decompose it by any available strength of battery. It would require an exposed point of metal and the passage of an electric spark in order to decompose the gutta-percha, and he had never seen any evidence of holes being burnt in that

way in a telegraph cable. The currents used in signalling did however increase any faults previously existing in the insulating material due to air holes, impurities, or mechanical injury received after the manufacture. At these points a certain fraction of the current passed from the copper conductor to the sea, and in its passage increased the fault both by its chemical action and by the heat developed. A larger and larger fraction of the current was thus diverted, until the fault, small at first, became so considerable that if powerful currents were used heat enough was developed even to melt the gutta-percha: in this way a considerable portion of the copper wire became exposed, and a considerable leak established. It had been the practice then to use more and more powerful currents, which aggravated the injury: and moreover positive currents instead of the ordinary negative currents used to be employed, because by the oxidation which they produced a temporary sealing up of the fault was effected; this however was done at the expense of the copper, which was gradually eaten away. At last by this action the copper was totally severed, and then and not till then all the signals failed entirely. This he believed had been what had taken place in almost all the failures where the cable itself had not been broken.

But although some failures had occurred from imperfections in the core or insulated wire, the cause of failure in the great majority of cases had been the failure of the outside covering; and he entirely concurred in considering that the outside covering was now the most important part of a submarine telegraph cable, because the interior portion could now he believed be satisfactorily manufactured, tested, and preserved. In regard to the durability of copper for the sheathing of a cable, one point that it was important not to overlook was the electrical condition of the copper itself, whether more or less electro-negative, which had a material bearing upon the durability of the metal. This condition appeared to be greatly affected by the temper of the metal, and in the case of ships' sheathing it varied considerably even in different parts of a single sheet of metal, which he thought would account for the unequal wear observed in different portions of the sheathing of a ship's bottom: a few bad places were not of so much consequence in a ship's sheathing, but would be of serious moment in the sheathing of a

telegraph cable, by destroying the strength of the outside covering and allowing the cable to break.

In reference to the difficulty that had been mentioned of paying out a cable safely when covered with iron wire sheathing, owing to the risk of a broken wire sticking out and catching on the paying out wheel, the "brush" as it was called, produced by the running up of the wire on these occasions, certainly looked formidable when seen for the first time; but in several hundred miles of telegraph cable that he had seen paid out he knew of no such instance which had been attended with any fracture or any apparent injury to the cable.

The CHAIRMAN moved a vote of thanks to Mr. Jenkin for his paper, which was passed, and also to the several manufacturers who had kindly lent the large number of specimens of submarine telegraph cables exhibited in connexion with the paper.

The two following papers, communicated through Mr. William Simpson of London, were then read, the discussion on the two being taken together :—

ON THE DOUBLE CYLINDER EXPANSIVE STEAM ENGINE.

BY MR. WILLIAM POLE, OF LONDON.

The greatest advances made in the improvement of the steam engine, as an economical means of obtaining motive power, have resulted from the application of the principle of expansion, the advantages of which are now well known and universally appreciated among engineers. This principle has hitherto been applied to the greatest advantage in engines with a single cylinder, used for pumping purposes, as in Cornwall. In these cases the peculiar nature of the motion admits of the steam being cut off after a small fraction of the stroke has been passed over, and allowed to expand during the remainder. When however the principle of expansion is applied in this mode to engines for producing rotary motion, some difficulties arise, which limit considerably the extent that the expansion may be carried to, and therefore reduce in a corresponding degree the economy attained.

The Double Cylinder Engine offers a mode of applying the expansive principle to rotary motion, which removes or at least greatly mitigates the objections to the single cylinder : and it is the object of the present paper to state the nature of the advantages of the double cylinder engine, to explain the principles on which they are based, and to show how these principles have been carried out in practice with satisfactory results.

The original invention of the double cylinder engine is intimately connected with the discovery and first application of the principle of expansion itself ; but the unfortunate disputes which for a long time prevailed in reference to this subject have somewhat obscured the history. Having had occasion however some years ago to investigate the matter, the author believes the following account represents the facts as accurately as they can be ascertained.

The double cylinder engine was invented by Jonathan Hornblower, a mechanical engineer of considerable eminence in Cornwall, who took an important part in the application of the steam engine in that district during the early part of Watt's career. The idea appears to have occurred to him early in the year 1776, if not before. He experimented upon a large working model, the cylinders of which were 11 and 14 inches diameter respectively; and he published his invention in 1781, describing it as consisting in the employment of two steam cylinders, the steam after it had acted in the first cylinder being employed a second time in the other, by permitting it to expand itself, the two cylinders being connected together by suitable steam ports and valves. At the same time he described also, shortly but clearly, several other inventions relating to the steam engine: one referring to surface condensing, which is so much applied in modern days; others to means of getting rid of the air and condensed water; and another invention was a steam piston, which, altered into a steam stuffing-box, is in common use at the present time. Here therefore was clearly developed the theoretical principle as well as the practical application of the expansion of steam; and it is beyond dispute that the first publication of the principle to the world was this of Hornblower's. The discovery of this principle however is usually ascribed to Watt, on the strength of a letter written by him to his friend Dr. Small of Birmingham as early as 1769, twelve years before Hornblower published his description; in that letter Watt gives a clear and explicit description of the general principle of expansion. Notwithstanding however the large practice Watt had about this time, it does not appear that he ever applied expansion with any view to economy in its use till 1776, when an engine at the Soho works was altered to work expansively. In 1778 another engine at Shadwell was experimented upon, and Watt published his invention in reference to expansion in 1782, eight months after the publication of Hornblower's. The over-zealous friends of Watt, who, in a spirit so contrary to that of the great man himself, have sought to exalt his fame at the expense of another's, have charged Hornblower with pirating the principle, from surreptitious information of Watt's experiments; but no proof was ever given of the accusation. It is not only highly

improbable in itself, but is altogether negatived by the fact that the originality of the invention on Hornblower's part was expressly admitted by Watt himself. It may therefore be concluded that the discovery of the expansive use of steam, one of the most important and valuable principles in the whole range of practical science, was original both with Watt and Hornblower; and although Watt has established the priority of the idea, the first publication of it to the world was made by Hornblower in the double cylinder engine.

After some years delay, Hornblower proceeded to manufacture his engines in Cornwall; and the miners perceiving that the double cylinder engine acted tolerably well took advantage of it somewhat largely, and in some cases endeavoured to make it supersede Watt's single cylinder expansive engine, which had also then been brought extensively into use. But as it was impossible to make Hornblower's engine work well, without using Watt's separate condenser, invented in 1769, the competition could not be kept up, and the double cylinder engine consequently fell for a time into disuse.

Both Watt and Hornblower had failed to perceive that, to work the principle of expansion to its full advantage, it was necessary that the steam should be admitted to the cylinder in the first instance at considerable pressure. Down to the year 1814, the pressure of the steam in the Cornish engines never much exceeded that of the atmosphere; and so little economy resulted in practice from the application of expansion with this initial pressure that it was found scarcely worth using at all; indeed after Watt's immediate connexion with the district ceased, expansion was rapidly becoming disused and forgotten. The merit of rescuing it from this neglect belongs to two Cornish men, Richard Trevithick and Arthur Woolf; who both about the same time introduced into their native district the true means of advantageous expansion, namely the use of high pressure steam. Trevithick applied this to Watt's single cylinder engine; Woolf applied it to Hornblower's double cylinder engine. The two forms of engine thus for the second time became rivals, and competed well with each other for many years; but it is only with Woolf's modification that the author is now concerned.

Woolf published his invention in 1804, while residing in London. It consisted simply in the application of high pressure steam to Hornblower's double cylinder engine, which he also made double-acting to fit it for rotary motion after the example set by Watt long before. It is obvious therefore that the name "Woolf's engine," by which it is so often designated, is quite erroneous. The engine is entirely and solely Hornblower's invention, and there is no more ground for calling it Woolf's than for calling the present Cornish engine Trevithick's; for Trevithick made the same change with this latter engine that Woolf did with the former, yet no one would on that account think of disconnecting Watt's name from his own engine; and on the same ground Hornblower ought not to be deprived of the credit which the association of his name with his own invention should secure to him. Woolf's ideas respecting the laws of the expansion of high pressure steam were very crude, and it is difficult to conceive how a man of such excellent practical knowledge could have deluded himself into the belief of theories so palpably absurd as those he laid down, upon which he based his statements as to the proposed advantage to be derived from the use of high pressure steam. But although he was so essentially in error on points of theory, he was not wrong in foretelling that much advantage might ultimately be gained by the use he proposed to make of high pressure steam; as was proved beyond a doubt when his engines came to be fairly tried. His strong point was skill in mechanical detail; and his improvements of the engine in this respect were almost innumerable, for there was scarcely a single part which did not receive some beneficial alteration at his hands. Woolf's first engine was erected in 1806 at Meux's brewery in London, to which establishment he was engineer, and subsequently others were fixed in various manufactories; but these did little more than serve him as experiments until 1813, when he returned to reside in Cornwall. Here he found a wide field open for his improvements; he entered in earnest into the manufacture of the engines, and they were highly successful. The new doctrine of high pressure steam produced quite a revolution in the consumption of fuel there; for he at once raised the duty from about 20 millions, at which Watt had left it (that is 20 million lbs. raised one foot high

with the consumption of one bushel or 94 lbs. of coal), to between 50 and 60 millions, thereby saving two thirds of the fuel employed.

But though Woolf was so successful, the Cornish engineers shortly began to see that Trevithick's plan of using high pressure steam expansively in the single cylinder engine promised equally good results with Woolf's, and at the same time got rid of the objectionable complexity of the double cylinder arrangement. Trials on a large scale, in which even Woolf himself was persuaded to assist, soon demonstrated this to be true; the more expensive construction began to be abandoned in the mines, and the Cornish engine gradually settled down into its simplest form; namely, a single engine on Boulton and Watt's construction, but with Trevithick's high pressure steam and high pressure boiler; which form it has retained to the present day. Thus although the double cylinder engine was the first in which the principle of expansion was originally introduced to the world, and about thirty years afterwards was also the first in which this principle was made effective and advantageous, yet in both cases it was ultimately superseded by the more simple form of engine.

It remains now to give some account of the third era of prominence attained by the double cylinder engine, in its revival at the present day. In this revival many modern engineers have aided; but the author considers it the safest course to confine himself to the statement of his own experience, leaving it to others to give an account of what they may have done.

In 1848 the Lambeth Water Works Company, on the advice of their engineer, Mr. James Simpson, took the bold measure of proposing to remove their source of supply to the bank of the Thames at Long Ditton above the tide way; and, as a part of this scheme, it became necessary to force the water by steam pumping power along a cast iron main, nine miles long and 30 inches diameter, from the source to the reservoirs at Brixton Hill. This problem was a difficult one, no experience on so great a length of large main having then been obtained. The great mass of water in motion along the main, combined with the fragile nature of the cast iron, rendered it essential that the motion should go on in the most

equable manner and that concussions or irregularities of pressure should be as much as possible avoided ; otherwise frequent fracture of the pipes, fraught with serious consequences to the district they passed through, might be looked upon as almost certain. At the same time, from the large steam power required, it became necessary that all possible improvements in regard to economy of fuel should be adopted. At that time the Cornish single cylinder expansive engine, which had been introduced into London by Mr. Wicksteed, had been somewhat extensively tried for waterworks purposes, and had justified its well known Cornish reputation for economy ; but as grave objections appeared to present themselves to its use in this case, on account of the irregularity of the single action, it was determined to ascertain whether the other form of expansive engine, the double cylinder, would not prove more applicable ; and since the importance of the case required the most careful consideration, the author was commissioned, in conjunction with Mr. David Thomson, to investigate the subject generally, with a view to the advantageous attainment of the desired economy.

In commencing this investigation it was found that the double cylinder engine had already been to some extent revived, and that modern examples of it, some of considerable size, were working in various parts of the country. These were visited and their action carefully examined ; but it did not satisfactorily appear that any engines then met with were sufficiently favourable instances of the application of the expansive principle. The expansion had not been carried to a sufficient extent to produce great economy, nor arranged in the best manner to attain equality of motion ; and the arrangement of the valves and passages was generally so defective as to cause great loss of power and waste of fuel. Notwithstanding these unfavourable results however an attentive study of the principles of the engine led to the conclusion that, with a well considered design carefully carried out into practice, the double cylinder arrangement promised not only to be eminently suited to the case in question, but also generally to offer a more beneficial application of the principle of expansion to engines for rotary motion than could be attained with a single cylinder. In accordance with these views, when the Lambeth Water

Works Extension scheme was carried into effect, four large double cylinder engines were designed of 600 total horse power, the working of which has fully justified the expectations entertained of their advantages; their use has been speedily and largely extended to other cases; and the soundness of the principles on which they were constructed may now be said to have been fully proved.

The general theory of the double cylinder engine is so well known that it is unnecessary to repeat it here; the author proposes therefore to confine his remarks to such points as are of interest and importance in elucidating the advantages of this form of engine.

In the first place, in comparing the double with the single cylinder engine it is a mistake to suppose that there is any theoretical advantage on either the one side or the other, in regard to the economical effect of the expansion. It was shown by Watt in an ingenious way at a very early period, and it is demonstrated in the appendix to this paper, that theoretically, if the steam be expanded to the same extent, the economical advantage to be derived from the expansion will be precisely the same, whichever form of engine be adopted for the application. And it further results from the principles of the engine that, for a given initial pressure of steam and a given degree of expansion, the power of the engine, measured by the work it will do in each stroke, depends on the size of the large cylinder only, and is precisely the same as that produced in a single expansive cylinder of the same content. The small cylinder has no effect in adding power, but is merely an appendage, useful only for modifying the arrangement of the expansion and equalising the steam's action during the stroke.

The important objection however against carrying expansion to any great extent in a single cylinder for rotary motion is the great irregularity of pressure at different parts of the stroke. For example, if the steam be expanded in a single cylinder to six times its original volume, by cutting it off when one sixth of the stroke has been passed over, the motive force acting on the piston will be six times as great at the commencement of the stroke as at the end. The accompanying theoretical diagram, Fig. 1, Plate 69, of the varying pressure of the

steam throughout the stroke, when expanded six times in a single cylinder, shows that, assuming the mean total pressure to be 100, the pressure at the commencement will be 215, and at the end only 36; giving an irregularity of 179. The calculation of this and the subsequent theoretical diagrams is explained in the appendix. It is evident that the effect of the great excess of pressure will be to give a heavy blow to the piston at the beginning of every stroke, which must produce violent concussions through the whole of the machinery and tend to produce much mischief and inconvenience in the working. In proportion as a greater degree of expansion is used, the evil will be greater. For example, if ten times expansion be used, the force of the blow at the commencement will be 303, while the mean pressure in the cylinder is still only 100 as before. For this reason in single cylinder engines it has been found difficult to carry the degree of expansion and the consequent economy to the same extent with the rotary as with the single-acting pumping engines. In the latter the piston and all its connexions are free to move under the action of the steam pressure; and therefore the excess of pressure at the commencement of the stroke is at once absorbed in giving velocity to the mass, and does no further harm: but in a rotary engine, the piston being controlled in its motion by the crank and flywheel resists the violent impact, which occurs at the point when it is least able to give way; and the consequence must inevitably be a violent strain, repeated many times every minute, which must ultimately have a prejudicial effect upon the machinery. The advantage of the double cylinder engine is that it mitigates this evil; for when its principles are properly understood and applied, it enables the economical benefit of a high degree of expansion to be obtained with much less irregularity of pressure than in the single cylinder.

In the original double cylinder engines of Hornblower and Woolf the steam was allowed to act first in the small cylinder at full pressure throughout the whole of its length, and then to expand into the larger one, the proportionate cubic content of the two cylinders thus defining the degree of expansion made use of: and it is believed that this method of working was that most commonly used down to the time of the investigations already referred to in 1848. But an enquiry into

the principles of action of the engine shows that it is most advisable not to allow the steam to enter the small cylinder during the whole stroke, but to cut it off after a certain portion of the stroke has been passed over, and to allow the expansion to commence at that point. And it is an important fact, which the author believes not to have been known until published by himself and Mr. Thomson in 1851, that there is a certain point of the stroke, depending on the degree of expansion made use of, at which it is more advantageous to cut off the steam than at any other; for the reason that the irregularity in the motive power, which it is so desirable to mitigate, is then reduced to a minimum.

For example, if the mean motive power of the engine be represented by 100, and the extent of expansion adopted be six times, then in a single cylinder engine the initial blow on the piston at the commencement of the stroke, as previously stated, will be represented by 215, as shown in the diagram, Fig. 1, Plate 69. In a double cylinder engine, if the steam is allowed to enter during the whole of the stroke of the small cylinder, the initial blow will be the same in amount as in the single cylinder engine, namely 215, as shown in Fig. 2; the duration of the blow however is only momentary, as compared with that in Fig. 1, where it continues through one sixth of the stroke. But if the steam is cut off in the small cylinder at 41 per cent. of the stroke, the initial blow is reduced to only 140, as shown in Fig. 3; and this is the minimum blow that can be obtained with the expansion of six times, for on cutting off earlier at 25 per cent. of the stroke the initial blow is increased again to 161. In the diagrams, Plate 69, the comparative motive power is shown in each case throughout the whole stroke of the engine, for the expansion of six times.

It thus appears that, as regards a degree of expansion of six times, if this expansion be effected in a single cylinder, the machinery of the engine will have to bear a sudden blow at the commencement of the stroke, as much as 115 per cent. greater than the mean force due to the effective power of the engine. Next, if a double cylinder engine be employed, and the steam be allowed to enter during the whole stroke of the small cylinder, but little improvement is effected; the blow at the commencement is as great as in the single cylinder, only lasting a

shorter time. But if the same engine be so arranged that the steam is cut off in the small cylinder at the proper point of the stroke, the initial blow may be reduced from 115 per cent. to only 40 per cent. in excess of the mean force; and thus a real and most beneficial improvement may be effected in the action of the engine. This most advantageous point of the stroke for cutting off is determined by calculation in the appendix, and it varies with the extent of expansion adopted in the engine.

The following table shows the best point of cut off under various degrees of expansion, with the corresponding results in the double cylinder and single cylinder engines. The first column gives the number of times the steam is to be expanded; the second shows the percentage of the stroke at which the steam will best be cut off in the small cylinder; the third, the corresponding proportionate area of the small cylinder in percentage of the large one, the length of stroke being the same in both; and the two last columns show the comparative advantage of the double over the single cylinder engine in respect to the excess of the initial blow over the mean motive force. The calculation of these results is explained in detail in the appendix.

Table showing Best Point of Cut Off in double cylinder engine with different degrees of expansion, and Comparative Initial Blow in double and single cylinder engines.

Number of times steam is expanded.	Best Point of Cut off in small cylinder. Percentage of stroke.	Capacity of small cylinder in percentage of large cylinder.	Comparative Initial Blow, the mean motive force being 100.	
			Double Cylinder engine.	Single Cylinder engine.
	Per cent.	Per cent.		
4 times	50	50	126	168
6 times	41	41	140	215
8 times	35	35	151	260
10 times	32	32	161	303

A comparison of the two last columns shows that for a high degree of expansion, such as eight or ten times, the excess of the initial blow over the mean force of 100 is less than one third as great in the double cylinder as in the single cylinder engine. It is clear that the

amount of this initial blow is the maximum strain on the whole of the machinery by which the steam power is transmitted from the piston to the flywheel, and it consequently determines the strength of the various parts necessary to resist this strain. Hence in proportion as the initial blow can be reduced, all these moving parts are required to be less massive in construction; and all are subject to much less violent causes of fracture and derangement in their working.

Another point of improvement to which the attention of the author and Mr. Thomson was prominently directed was the arrangement of the valves and steam passages in the double cylinder engine. In the engines they had the opportunity of examining, the system of valves commonly used was not only complicated, inconvenient, and expensive in construction, but also wasteful in action; the great size and disadvantageous arrangements of the passages caused considerable waste of steam and consequent loss of power and fuel. There is a peculiarity in the double cylinder engine in its requiring a pipe or passage of some kind through which the steam must travel from one end of the small cylinder to the opposite end of the large one; and this passage should evidently be as small in content as possible, consistently with allowing the free passage of the steam. When the communication is opened at the end of the stroke, the steam passing from the small cylinder has to expand and fill this passage before it enters the large cylinder; and if the passage be large, the steam must necessarily suffer a reduction of pressure in so doing, which must seriously diminish its effective action on the large piston during the future stroke, and so cause much loss. In some engines the author found this loss so great as to waste nearly half the power of the engine; and even in the best that were examined such a considerable percentage of loss occurred as almost to neutralise the benefit of expansion altogether.

Much attention was therefore given to this point in designing the new engines; and it was found essential to the success of the engines that some arrangement of valves should be adopted which should satisfy the following conditions:—first, that they should be of the simplest possible character and free from liability to derangement;

second, that they should admit of the steam being cut off from the small cylinder at such a point as might be necessary to secure the required regularity in the motive power of the engine; and third, that they should give the clearance spaces the smallest content possible, and in particular should allow the passage between the two cylinders to be direct and unimpeded and of no larger capacity than absolutely necessary for the passage of the steam. It was further found conducive to economy that the passage between the two cylinders should if possible never be opened either to the high pressure steam or to the condenser, and should moreover be carefully protected from cooling.

A construction of valve was accordingly introduced which combined all these conditions; and was found in its practical working to be very satisfactory. The detailed description of this valve will be given in the succeeding paper by Mr. Thomson.

APPENDIX.

Analytical investigation of the principles of the Double Cylinder Expansive steam engine.

In this investigation it will be convenient to assume that the length of stroke in both the large and small cylinder is the same, and that the pistons move simultaneously with equal velocity, as would be the case if they were both attached to the same point of the beam. In the general investigation also the clearance passages must be omitted; for as their effect depends on the arrangement of the valves, they must be considered specially in each individual instance. Now let

A = area of large cylinder.

a = „ small „

L = length of stroke.

l = length of stroke passed over before the steam is cut off in the small cylinder.

P = total pressure of steam per square inch in the small cylinder before cutting off: this is assumed constant through the space l .

p = back pressure of imperfect vacuum per square inch in the large cylinder.

x = space passed over by the pistons at any point of the stroke, reckoned from the commencement of the stroke.

y = joint effective pressure on the two pistons at the end of the portion x of the stroke.

u_1 = work performed during the portion l of the stroke.

u_2 = " " " remainder "

$U = u_1 + u_2$ = total work performed during the whole stroke.

The whole stroke naturally divides itself into two portions: first *before*, and secondly *after*, the steam is cut off in the small cylinder.

First, *before* the steam is cut off in the small cylinder. Supposing the pistons are making the downstroke, the total forward pressure above the small piston will be uniform and equal to aP . The back pressure under it will be variable, and will be the same per square inch as the pressure above the large piston, since each end of the small cylinder communicates through the valve with the *opposite* end of the large cylinder. The value of this pressure must be found by considering what has taken place in the preceding upstroke. The steam of pressure P had first filled the small cylinder to a cubic content al ; and at the end of the upstroke this volume had expanded into a space aL . Then when the pistons have performed any portion x of their downstroke, the space occupied by the expanding steam will be reduced by the descent of the small piston and increased by the descent of the large one, so that it will become $aL + (A - a)x$. According therefore to Mariotte's law, which may be taken as sufficiently accurate for the purpose, the pressure per square inch of the steam flowing from the bottom of the small cylinder into the top of the large one, after any portion x of the downstroke has been passed over, will be

$$P \frac{al}{aL + (A - a)x} \quad (1)$$

and this, multiplied by a , will be the total back pressure against the small piston at that point of the stroke. The total forward pressure on the top of the large piston will be the same expression (1) multiplied by A ; and the total back pressure of the imperfect vacuum underneath the large piston will be $A p$.

Hence, adding the effect of the two pistons together to obtain the joint effective pressure y at the end of the portion x of the stroke, before the steam is cut off,

$$y = a P + (A - a) \frac{a P l}{a L + (A - a) x} - A p \quad (2)$$

The work performed therefore during the portion l of the stroke will be the integral of $y dx$ between the limits l and 0, or

$$u_1 = a P l \left(1 + \log \frac{a L + (A - a) l}{a L} \right) - A p l \quad (3)$$

Secondly, *after* the steam is cut off in the small cylinder. Here the forward pressure in the small cylinder is variable; for after a length of stroke x the volume of steam which was originally $a l$ will be increased to $a x$, and the pressure per square inch will consequently be diminished to $P \frac{l}{x}$; so that the total forward pressure on the small piston will be $a P \frac{l}{x}$. The back pressure on the small piston and the forward pressure on the large one will be found by the same expression (1) as before; so that the joint effective pressure y on the two pistons, after the steam is cut off, will be

$$y = a P \frac{l}{x} + (A - a) \frac{a P l}{a L + (A - a) x} - A p \quad (4)$$

And the work performed during this latter portion of the stroke will be the integral of $y dx$ between the limits L and l , or

$$u_2 = a P l \log \frac{A L^2}{a L l + (A - a) l^2} - A p (L - l) \quad (5)$$

Adding therefore equations (3) and (5) together, the total work developed during one entire single stroke of the two pistons will be

$$U = u_1 + u_2 = a P l \left(1 + \log \frac{A L}{a l} \right) - A p L \quad (6)$$

It may now readily be seen that the theoretical effect of the expansion is the same with the double as with the single cylinder engine. For in this last equation $\frac{A L}{a l}$ represents the final extent of the expansion, or the number of times the steam is increased in volume from the time it is cut off in the small cylinder to the end of its action in the large one. If this be represented by E , so that $E a l = A L$, then if the dimensions of the large cylinder be used, the work done in a single stroke will be

$$U = \frac{A L P}{E} (1 + \log E) - A L p \quad (7)$$

which is precisely the same expression as represents the work of steam used expansively in a single cylinder whose area is A and length of stroke L , and in which the steam is cut off at $\frac{1}{E}$ th part of the stroke. The work performed by a given quantity of steam is therefore exactly the same in the double cylinder engine as in the single cylinder engine, with the same extent of expansion in both cases, as was stated in the paper.

The last equation (7) also furnishes the proof of the further principle stated in the paper, namely that, for a given initial pressure of steam and a given degree of expansion, the power of the engine, measured by the work it will do in each stroke, depends solely on the size $A L$ of the large cylinder.

The volume of steam at the initial pressure P used to perform the work U is $\frac{A L}{E}$; from which the *duty* of the engine may be found in the usual way.

If the length of stroke be taken in feet, the areas of the pistons in square inches, and the pressure in lbs. per square inch, according to the usual practice, and if N be the number of single strokes per minute, then the theoretical *horse power* of the double cylinder engine will be

$$\text{Horse power} = \frac{A L N}{33000} \left\{ \frac{P}{E} (1 + \log E) - p \right\} \quad (8)$$

It must be remembered that P is the pressure of steam in the small cylinder during the period before cutting off, and not the pressure in the boiler which is generally much higher.

It can now be shown that, for an engine of given power and given expansion, there is a point, as stated in the paper, at which the steam may be cut off in the small cylinder, so that the excess of power at the commencement of the stroke may be a minimum. Simplifying equation (2) by omitting the imperfect vacuum, and making $x = 0$, the joint effective pressure y on the two pistons at the commencement of the stroke is

$$y = P \left\{ a + (A - a) \frac{l}{L} \right\}$$

Let $\frac{l}{L}$, the fraction of the stroke at which the steam is to be cut off, be represented by z , the independent variable. Then since E

representing the extent of the expansion, as before, is to be constant, and since the power of the engine, which is measured by the size of the large cylinder, is also to be constant, the area of the small cylinder a will be variable and equal to $\frac{A}{Ez}$; whence the total initial pressure y is

$$y = A P \left(\frac{1}{Ez} + z - \frac{1}{E} \right) \quad (9)$$

which must be a minimum. Treating this in the usual way by differentiating and putting $dy = 0$, the simple result arrived at is that the initial force or blow is a minimum when

$$z = \frac{1}{\sqrt{E}} \quad (10)$$

that is when the area of the small cylinder is so proportioned to that of the large one as that the fraction of the stroke at which the steam is cut off shall be equal to the reciprocal of the square root of the given degree of expansion.

Substituting this value in equation (9), the *initial blow* at the commencement of the stroke in the double cylinder engine will be

$$y = A P \left(\frac{2 \sqrt{E} - 1}{E} \right) \quad (11)$$

whereas in a single cylinder engine of the same power and expansion the initial blow will be

$$y = A P \quad (12)$$

which is greater than that given by the preceding equation, since E is necessarily greater than 1; and a comparison of these two equations in any individual case will show the exact advantage of the double cylinder over the single cylinder engine.

The *mean* motive power in either engine will be found by dividing the total work U in equation (7) by the length of stroke L , neglecting the imperfect vacuum; which will give

$$\text{Mean motive power} = \frac{A P}{E} (1 + \log E) \quad (13)$$

The last two columns of the table given in the paper are calculated from the two previous equations (11) and (12), taken in connexion with the last equation (13). The third column, giving the proportionate size of the small cylinder as compared with the large one, is obtained from the equation

$$\frac{a}{A} = \frac{1}{Ez} = \frac{1}{\sqrt{E}} \quad (14)$$

and the second column, calculated from equation (10), is identical with the third, since these equations (10) and (14) are the same. The ordinates or vertical dimensions in the theoretical diagrams Figs. 2 and 3, Plate 69, for the double cylinder engine, are calculated from equations (2) and (4), omitting the imperfect vacuum; and in Fig. 1, for the single cylinder engine, they are simply taken inversely as the portion of the stroke passed over from the commencement.

ON DOUBLE CYLINDER PUMPING ENGINES.

BY MR. DAVID THOMSON, OF LONDON.

The Double Cylinder Pumping Engines referred to in the previous paper by Mr. Pole as having been erected by Messrs. Simpson at the Lambeth Water Works, Thames Ditton, were designed and executed under the superintendence of the author of the present paper, in which it is intended to give a general description of the engines, with a few practical remarks suggested by the experience of their performance.

The general arrangement of these engines is shown in Fig. 1, Plate 70. They are beam engines, having the double cylinders A B at one end of the beam, and a crank C and connecting rod at the other end; four engines of 150 horse power each are fixed side by side, arranged in two pairs, each pair working on to one shaft, with cranks at right angles, and a flywheel D between them. The strokes of the crank C and of the large cylinder A are equal; while the small cylinder B, which receives the steam direct from the boiler, has a shorter stroke, and its effective capacity is nearly one fourth that of the large cylinder. The pumps E are connected direct to the beams near the connecting rod end by means of two side rods, between which the crank C works. The pumps are of the combined plunger and bucket construction, and are thus double-acting although having only two valves: the author believes that this kind of pump, which is now in general use, was first introduced by him at the Richmond and Bristol Water Works in the year 1848. The following are the principal dimensions of the engines:—

Diameter of large cylinder	46 ins.
„ small cylinder	28 ins.
Stroke of large cylinder	8 ft. 0 ins.
„ small cylinder	5 ft. 6½ ins.
Diameter of pump barrel	23½ ins.
„ pump plunger	16½ ins.
Stroke of pump	6 ft. 11½ ins.
Length of beam between extreme centres	26 ft. 6 ins.
Height of beam centre from floor	21 ft. 4 ins.

L 2

The principal peculiarity of these engines is in the valves and valve gear: the valves are so constructed that one valve effects the distribution of the steam in each pair of cylinders. Fig. 2, Plate 71, is a vertical section through the centres of the two cylinders and valve, which are drawn as if situated in the same straight line, for convenience of illustration; but the correct position of the valve in connexion with the two cylinders is shown in the sectional plans, Figs. 3 and 4, Plate 72, taken through the steam ports of the large and small cylinders respectively. The valve F, of which the top end is shown enlarged in Fig. 7, Plate 73, consists of four small pistons GG, 14 inches diameter, connected together by a pipe H which forms the passage whereby the steam is conveyed from one end of the small cylinder to the opposite end of the large cylinder. The action of the valve is shown by the two diagrams, Figs. 5 and 6, Plate 73, which represent its two extreme positions at the commencement of the up and down strokes. The steam from the boiler enters the annular space I surrounding the middle of the valve; and the communication with the condenser J, Fig. 1, is at KK, beyond the top and bottom ends of the valve. With the valve in its lowest position, as shown in Figs. 2 and 5, Plates 71 and 73, the steam from the boiler is admitted into the bottom of the small cylinder B, for making the up stroke; and the steam from the top of the small cylinder is exhausted through the hollow pipe H of the valve into the bottom of the large cylinder A, while the top of the large cylinder exhausts direct into the condenser, beyond the top end of the valve. Figs. 6 and 7, Plate 73, show the valve in its highest position, for admitting the steam in the corresponding manner at the beginning of the down stroke.

The cylinder ports are rectangular, with inclined bars across the faces to prevent the packing rings of the valve from catching against the edges of the ports: and the bars are made inclined instead of vertical in order to avoid any tendency to grooving the valve packing. The openings of the port extend two thirds round the circumference of the valve in the ports of the large cylinder, as shown in Fig. 3, Plate 72; but they extend only half round in the ports of the small cylinder, as shown in Fig. 4. The packing of the valve consists of the four cast iron rings GG, Fig. 7, Plate 73, which are cut at one

side exactly as in an ordinary piston, the joint being covered by a plate inside. A considerably stronger pressure of the rings against the valve chest is required than was at first expected, because the openings of the steam ports extend so far round the valve; and for this purpose springs are placed inside the packing rings to assist their own elasticity. This construction of valve has the advantage of admitting of great simplicity in the castings of the cylinders; and also allows of the whole of the valve work being executed in the lathe, which is generally both the cheapest and most correct kind of work in an engineering workshop. These valves are worked by cams, which are not well adapted for engines working at high speed; and this led the author in the construction of some recent double cylinder engines to adopt valves and valve gear of a different construction; but he has not been able to design any which surpass or even equal these in the economical distribution of the steam.

The principal object aimed at in the construction of this piston valve was the reduction to a minimum of the loss of pressure which the steam undergoes in passing from the small cylinder to the large one. This is here accomplished by making the passage of moderate dimensions and as direct as possible; and also by preventing any communication of this passage with the condenser, so that when the steam from the small cylinder enters the passage, the latter is already filled with steam of the density that existed in the large cylinder at the termination of the previous stroke. In constructing the engines some doubt was entertained as to the best size of passage, in order on the one hand to avoid throttling the steam, and on the other to obviate as much as possible the loss of steam in filling the passage. The size adopted was a pipe 6 inches in diameter, or $\frac{1}{60}$ th of the area of the large cylinder, for a speed of piston of 230 feet per minute in the large cylinder; and this is believed to be about the best proportion, the entire cubic content of the whole passage in the valve amounting to 3944 cubic inches. The indicator diagrams, Figs. 8 to 11, Plates 74 and 75, show that with this construction of valve there is very little or no throttling of the steam; and also that there is but a very moderate drop in the pressure as the steam passes from the small cylinder into the large one. In this respect the valve completely

answered the expectations entertained of it, and left little further to be desired on this point.

The accompanying indicator diagrams, Figs. 8 to 11, Plates 74 and 75, taken from the Lambeth Water Works engines, show the action of the steam throughout the stroke.

In Fig. 8, Plate 74, the upper diagram is that taken from the bottom of the small cylinder, and the lower is the corresponding diagram from the top of the large cylinder. Fig. 10, Plate 75, is the diagram taken at the same time from the top of the small cylinder, to which however there is none corresponding from the bottom of the large cylinder; but as the diagrams from the two ends of the small cylinder so nearly correspond, it may be presumed that a diagram taken from the bottom of the large cylinder at the same time would have been very nearly the same as that from the top, shown by the lower diagram in Fig. 8.

In Fig. 9, Plate 74, the upper diagram is that taken from the top of the small cylinder, and the lower is the corresponding diagram from the bottom of the large cylinder; while Fig. 11, Plate 75, is the diagram taken at the same time from the top of the large cylinder, to which however there is no corresponding diagram from the bottom of the small cylinder. The dotted lines in Figs. 8, 9, and 10, represent the exhaust line in the small cylinder reversed, so as to show by direct measurement of the distance between this and the top line of the diagram what is the effective or working pressure on the small piston at any part of the stroke.

In order that these diagrams may be compared with theory, it is necessary to know the cubic contents of the cylinders with the given lengths of stroke, of the clearances at the ends of the cylinders, and of the different parts of the steam passages. The following are the capacities of these spaces:—

	Cub. Ins.	Cub. Ins.
Capacity of small cylinder, 5 ft. 6 $\frac{1}{2}$ ins. stroke		40870
Clearance at end of small cylinder	808	
Space in port between valve and small cylinder	805	
Total space between valve and small piston		1113
Capacity of large cylinder, 8 ft. stroke		159542
Clearance at end of large cylinder	831	
Space in port between valve and large cylinder	2844	
Total space between valve and large piston		3675
Capacity of all passages in valve		3944
Sum of last two capacities		<u>7619</u>

Hence the steam escaping from the small cylinder has to expand into an additional space of 7619 cubic inches before it reaches the large piston.

The following table shows the principal results deduced from these indicator diagrams, in the calculation of which it has been assumed that the space occupied by the steam when expanded is inversely as the pressure; and also that the valve and pistons were steam-tight when the diagrams were taken, which is believed to have been nearly the case. For the sake of simplicity also the steam enclosed in the valve passage has been neglected, and the passage is supposed to be empty when the steam from the small cylinder enters it. The effect of the clearances and steam passages has been taken into account in calculating the expansions.

These indicator diagrams show in different degrees a few results which the author has constantly observed in all the indicator diagrams he has taken from double cylinder engines. In the first place, the pressure of the steam at the end of the stroke, instead of falling short of what it ought to be by the theoretical expansion curve, always exceeds that amount. In Fig. 8, Plate 74, this excess is as much as 80 per cent., and in Fig. 9 it is 23 per cent. of the actual final pressure. This fact has been often observed before to a smaller extent in single cylinder engines, and has been said to be peculiar to cylinders without jackets or external means of keeping up their heat. But in this case both cylinders were jacketted, and the jackets were supplied with steam of a higher pressure than the maximum pressure in the cylinders. It might be supposed that the increased pressure at the end of the stroke

*Table of Results**Deduced from the Indicator Diagrams, Figs. 8 and 9, Plate 74.*

	Fig. 8.	Fig. 9.
1. Percentage of stroke at which steam is cut off in small cylinder	25 per cent.	40 per cent.
2. Total expansion at end of stroke in small cylinder, in terms of bulk before expansion	3.78	2.41
3. Amount of expansion on passing from small to large cylinder, in terms of bulk before escaping from small cylinder	1.18	1.18
4. Total expansion at end of stroke in large cylinder, in terms of original bulk	15.15	9.66
5. Total amount of efficient expansion, in terms of original bulk	12.80	8.19
6. Total pressure of steam per square inch at point of cutting off	32 lbs.	41 lbs.
7. Theoretical total pressure at end of stroke of small piston	8.4 lbs.	17.0 lbs.
8. Actual total pressure shown by diagram	10.6 lbs.	18.0 lbs.
9. Excess of actual over theoretical in percentage of actual pressure	21 per cent.	6 per cent.
10. Theoretical loss of pressure in passage from small to large cylinder	1.7 lbs.	2.6 lbs.
11. Actual loss shown by diagram	2.5 lbs.	4.5 lbs.
12. Theoretical total pressure at end of stroke of large piston	2.1 lbs.	4.2 lbs.
13. Actual total pressure shown by diagram	3.0 lbs.	5.5 lbs.
14. Excess of actual over theoretical in percentage of actual pressure	30 per cent.	23 per cent.
15. Mean pressure on crank pin from both cylinders	15240 lbs.	22400 lbs.
16. Maximum ditto	27838 lbs.	36058 lbs.
17. Ratio of maximum to mean	1.83 to 1.00	1.61 to 1.00
18. Ratio of maximum to mean pressure on crank pin in a single cylinder engine with the same total amount of efficient expansion (art. 5), the clearances and ports bearing the same proportion to working capacity of cylinder, namely 1-40th part; this ratio is calculated from the ordinary logarithmic expansion curve	4.00 to 1.00	2.75 to 1.00
19. Efficiency of steam contained in large cylinder at end of stroke, as shown by diagram, if used without expansion, taken as	1.00	1.00
20. Actual efficiency of same steam as employed in both cylinders, as shown by diagram	2.70	2.90
21. Theoretical efficiency of same steam if expanded to same degree as total amount of efficient expansion (art. 5)	3.56	3.10

was due to the heat imparted from the jackets either superheating the steam or converting the watery vapour mixed with it into true steam; and probably the latter is the cause of a small part of the observed effect: but in the author's opinion it is not likely that sufficient heat could be communicated from the jackets to produce an increase of 23 per cent. in the actual final pressure, much less of 30 per cent. This is the more unlikely because on several occasions the condensed water from the jackets has been collected and found not to exceed half a gallon per hour. The experiments made on the quantities of water passed from the boilers give uniformly the result, that a considerably larger quantity of water passes from the boilers than is accounted for by the indicator diagram, taking the quantity and pressure of the steam just before it escapes to the condenser as the basis of calculation. In some trials made within a few days of the indicator diagram Fig. 8, Plate 74, being taken, the excess of water thus disappearing from the boilers was about 37 per cent. It appears however to the author that this constant excess of the actual over the theoretical final pressure of the expanded steam is still not satisfactorily explained. To suppose that the valve was leaking might account for it; but besides great care having been taken to avoid this source of error, it can hardly be supposed that the valve was always leaking more than the pistons.

Secondly, although the pressure of the steam in the cylinders in these engines always exceeds what would be given by theory, yet the loss of pressure in passing from the small cylinder to the large one always exceeds what would be expected from theory. This fact holds as universally as the previous, in the author's experience, although by no means to a uniform extent.

Thirdly, the table shows the great practical advantage that the double cylinder engine possesses in moderating the extreme strains on the machinery which are produced when expansion is carried to a great extent in a single cylinder: the maximum pressure on the crank pin from both cylinders is here only 83 per cent. greater than the mean in the diagram Fig. 8, and only 61 per cent. greater in the diagram Fig. 9. It is indeed impossible in practice to carry expansion in one cylinder to so high a degree as is shown in these diagrams. Although

single cylinder engines are frequently said to be expanding ten times, the author has not known any instance of their being so worked continuously, but only occasionally and experimentally; and in no case that he is acquainted with has the expansion ever been more than nominally to the extent of ten times, that is the steam has been cut off at 1-10th of the stroke from the commencement. In such a case the size of the valve passages and clearance of the piston amount to so large a proportion of the steam in the working part of the cylinder at the moment of cutting off that a nominal expansion of ten times is often in reality not more than six or seven times. In the small cylinder of the double cylinder engines now described the passages and clearances are reduced to a minimum, and are much smaller than in most single cylinders of the same size; and yet if the steam were here cut off at 1-10th of the stroke these passages would amount to one fourth of the volume of the steam contained in the cylinder at the moment of cutting off, and the expansion in this cylinder instead of being ten times would be only about eight times. This is a point too generally neglected in estimating the merits of different engines or discussing the results of indicator diagrams.

To ascertain the amount of friction in these engines the author has made many experiments, and has found that, when the engines are new and working at perhaps little more than half their power, the loss in comparing the work done with the indicator diagrams amounts to as much as 25 per cent. of the indicated power; but in these cases the pistons have been too tight in the cylinders, and when this error has been corrected and the engines worked up to their regular work all the losses are brought down to from 12 to 15 per cent. of the indicated power. This includes the friction of both the engines and the pumps, the working of the air pumps, feed pumps, cold water pumps, and pumps for charging the air vessels with air.

On the whole the author is of opinion that where expansion is carried to an extent of only three or four times, the single cylinder form of engine is simpler and better than the double cylinder; but where expansion is required to a much higher degree, the double cylinder presents the only way of carrying it out successfully in practice. When the double cylinder is adopted an ordinary expansion

of not less than ten times should be effected, if it is desired to get a result corresponding with the additional complication incurred. The theory of the action of steam jackets appears still somewhat doubtful, but there can be no doubt that with high expansion in two cylinders they are absolutely essential to a favourable economical result.

With regard to the economy of fuel attained by the double cylinder engines, it may be stated that the four pumping engines at the Lambeth Water Works are fixed in one house and are employed in pumping through a main pipe 30 inches diameter and about nine miles in length; and when all the engines are working together at their ordinary speed of 14 revolutions per minute, the lift on the pumps as measured by a mercurial gauge is equal to a head of about 210 feet of water. Under these circumstances they were tested by Mr. Field soon after being finished, in a trial of 24 hours' duration without stopping. The actual work done by the pumps during this trial was equal to 97,064,894 lbs. raised one foot high for every 112 lbs. of coal consumed; in addition to which this consumption included the friction of the engines and pumps, and the power required to work the air pumps, feed and charging pumps, and the pumps raising the water for condensation. The coal used was Welsh, of good average quality.

The economy in consumption of fuel during this trial and in the subsequent regular working of these engines, together with the satisfactory performance generally of the engines and pump work, induced the Chelsea Water Works Company and also the New River Company each to erect in 1854 a set of four similar engines, which were made almost exactly the same as the Lambeth Water Works engines already described, with the exception that a jacket of high pressure steam was in these subsequent engines provided under the bottoms of the cylinders, which had not been done with the previous engines. The pumps were also different in size to suit the different lifts.

The New River engines were tested soon after being completed, and the result reported was 113 million lbs. raised one foot high by 112 lbs. of Welsh coal. But this duty was obtained from a trial of only 7 or 8 hours' duration, which is too short to obtain very

trustworthy results ; and similar circumstances the author believes have given rise to the extraordinary statements that have sometimes been made regarding the duty obtained from steam engines.

The set of engines made for the Chelsea Water Works was the last finished, and on completion the engines were tested by Mr. Field in the same manner as the Lambeth engines, by a trial of 24 hours' continuous pumping. The coal used was Welsh, as before, and the duty reported was 103·9 million lbs. raised one foot high by 112 lbs. of coal. This, as in the previous instance, was the duty got from the pumps in actual work done, no allowance being made for the friction of the engines and pumps, and the power required to work the air pumps, cold water pumps, &c. At the time of these engines being tested the loss by friction and by working the air pumps, &c., averaged about 20 per cent. of the power as given by the indicator diagrams ; so that if the duty had been estimated from the indicator diagrams, as is usual in marine engines, it would have been $103\cdot9 \times \frac{100}{80}$ or about 130 million lbs. raised one foot by 112 lbs. of coal, which is equivalent to a consumption of 1·7 lbs. per indicated horse power per hour.

Mr. POLE said that in the investigation of the double cylinder engine he had been desirous of entering rather fully into its history, which had previously been involved in some obscurity. Few seemed to be aware of the extent of Hornblower's connexion with the engine, which was generally called Woolf's, although it was certainly Hornblower's invention ; and the principle of expansion, one of the most important principles in the steam engine, was first introduced to the world in Hornblower's engine. The revival of this same engine at a subsequent period was due to Woolf, who simply applied high pressure steam to it, as was done also about the same time by Trevithick to the single cylinder engine in Cornwall ; in the latter case the circumstances were so far different from those of other engines that the single cylinder engine was here undoubtedly the best for the purpose to which it was applied.

The double cylinder engine, as now practically carried out in the manner described in the paper last read, proved a very useful arrangement, by affording the means of carrying the important principle of expansion to a much greater extent than was practically possible in the single cylinder engine. In a single cylinder engine, when applied to pumping without a crank and flywheel, it was indeed possible to make use of a considerable degree of expansion, because the blow which then inevitably came at the commencement of the stroke was immediately absorbed by the inertia of the mass: but when the piston was controlled by a crank and flywheel he thought experience proved that it was scarcely possible to expand more than four or five times without producing a very great strain on the machinery; beyond that expansion the engine could not be made strong enough, and the blow was what no engineer would like to incur. This was made clear in the three theoretical diagrams exhibited, (Plate 69,) which were all constructed for the same total amount of expansion of the steam, namely six times. The first diagram showed that in the single cylinder engine the initial blow was 2.15 times the mean pressure throughout the stroke, and the force of the blow continued undiminished during one sixth of the stroke, after which the pressure dropped according to the regular expansion curve. The second diagram gave the combined effect of the two cylinders in the double cylinder engine, when the steam was kept on at full pressure throughout the entire stroke in the small cylinder: this was the original plan in the use of two cylinders, and the plan generally followed; but the diagram showed that the initial blow was here still the same as in the single cylinder engine, namely 2.15 times the mean pressure, the steam then passing at full pressure into the large cylinder at the moment of commencing the stroke; and although the pressure immediately fell off rapidly, instead of continuing during any length of the stroke, yet the machinery had necessarily to be made as strong as before, in order to stand the same initial blow, so that no practical advantage was gained. His object however had been to show in the paper that the initial blow might be greatly reduced and its injurious effect avoided by first expanding the steam partially through a portion of the stroke in the small cylinder, and then

completing the expansion in the large cylinder ; and also to show that by the adoption of this plan a point of cut off could be found at which the initial blow would be reduced to the minimum. The third diagram gave the result of cutting off the steam at the most advantageous point in the small cylinder, namely 41 per cent. of the stroke, whereby the initial blow was reduced to the minimum, being then only 1·40 times the mean pressure throughout the stroke, instead of 2·15 times as previously, and the line was much more equable throughout the stroke, approaching much more nearly to the mean pressure ; but an earlier cut off would have the effect of again raising the force of the initial blow. These theoretical results were fully borne out by the practical results obtained in the double cylinder pumping engines that had been described, in which the principle of expansion was now carried to a greater extent than would be possible in a single cylinder engine with crank and flywheel, and without being attended with the disadvantages that a single cylinder would entail.

The CHAIRMAN enquired what experience there had been as to the durability of the long cylindrical slide valve between the two cylinders in the double cylinder engine.

Mr. THOMSON replied that in the case of the Chelsea and the Lambeth Water Works engines the valves had proved quite as durable as the ordinary pistons made with metal packing rings were found to be. But in the engines at the New River Water Works the valves had not been so durable, nor had the pistons, and much inconvenience was suffered from this circumstance ; the reason had been found to be some peculiarity in the tallow used for lubrication, which caused the substance not only of the valves but also of the pistons to become eaten away. Now however, in place of the tallow previously used, animal fat procured in an unmanufactured state had been employed for the last twelve months, which had produced a great improvement in the durability of the valves and pistons, and the metal was now not nearly so much acted upon as it was before.

The CHAIRMAN asked what was the initial pressure of steam at the commencement of the stroke, and also the pressure in the boilers : and whether the actual final expansion of the steam was really as much as fifteen times.

Mr. THOMSON replied that in the engines from which the indicator diagrams were taken the boiler pressure was 40 lbs. per square inch above the atmosphere, and the initial pressure of the steam in the small cylinder was 35 lbs. The expansion in the first indicator diagram appeared to be 16 times, if merely the point of cut off were taken into consideration; but by including the effect of the capacity of the ports the actual expansion was 15 times, and if the useless effect of the expansion of the steam into the valve between the cylinders were also deducted, the total efficient expansion was found to be 13 times nearly; that is the volume occupied in the cylinders alone by the steam at the end of the stroke was 13 times as great as at the point of cut off. The steam would therefore be in reality expanded to that extent if its expansion followed the regular logarithmic curve; but the indicator diagram showed that the final pressure at the end of the stroke was 30 per cent. in excess of the theoretical pressure corresponding to the total expansion of 15 times, and therefore the actual expansion was proportionately less.

Mr. J. GRANTHAM enquired whether the steam was superheated in the engine from which the indicator diagrams had been taken.

Mr. THOMSON said the steam was not superheated, except by the heat obtained from the steam jacket of the cylinders which was filled with steam at the boiler pressure.

Mr. J. GRANTHAM thought that would probably account both for the pressure of steam being raised at the end of the stroke above the theoretical pressure, and also for the loss of water from the boiler, which had been stated to amount to 37 per cent. in excess of the consumption of water as calculated from the volume of steam contained in the small cylinder at the point of cut off. This extra amount of water must evidently have been carried off from the boiler mixed with the steam by priming, and then became evaporated at the end of the stroke by the heat from the steam jacket: but if the steam had been superheated immediately on leaving the boiler, before entering the cylinder, no water would have passed over with it, and there would have been no loss of water from the boiler, while the pressure would have followed the regular curve during the expansion.

The progress of the application of expansion in the steam engine, of which so interesting an account had been given, was a remarkable history, and seemed to have been divided into three distinct eras, the original idea of expansion having virtually died out after its first promulgation, until revived in 1814 by Trevithick and Woolf in connexion with a higher pressure of steam; then it again fell into neglect, and the great majority of engines were worked with little or no expansion whatever; and it was only within the last few years that the subject had now been again revived. The principle of expansion was one of such great practical importance that it required the most attentive consideration in all classes of steam engines. He remembered seeing at Stroud about twenty years ago a small double cylinder engine of about four horse power, which had been put up about thirty years previously by Woolf himself; it was employed in a brewery, and had a large cast iron boiler with some cast iron tubes through it, and the boiler was apparently as good as ever after thirty years' work, during which it had been going on without repairs. The engine was working with high pressure steam, about 60 lbs. per square inch above the atmosphere, and showed a remarkable economy in fuel, quite unequalled by any of the numerous other engines employed in the woollen manufacture in that neighbourhood: the latter however, though good engines, were all worked on the common low pressure system, and in none of them was the use of high pressure steam with expansion ever adopted for about twenty years after the erection of Woolf's small engine. A second engine on the same plan was however at length put up there, of about 30 horse power, carrying out the principle of expansion with high pressure steam; and this engine had at the time he saw it been working for nearly ten years consuming only about $2\frac{1}{2}$ lbs. of coal per horse power per hour, whereas many engines in the neighbourhood were using as much as 12 lbs.: yet no one else had at that time attempted to repeat the engine, notwithstanding the extent of steam power employed in the neighbourhood. This was an illustration of the indifference with which so important a subject had been treated, and not in that district alone, but throughout the entire country; but now that it was again revived, the question could not be discussed too frequently,

not only as regarded manufacturing purposes, but more especially in reference to marine engines.

From an examination of the various steam engines exhibited in the present International Exhibition he was confirmed in the opinion that the expansive use of steam was much more fully carried out on the continent than in this country, probably arising from the greater cost of fuel there. On the continent the double cylinder engine was in common use and had been so for many years, and in some localities he believed it was used exclusively. It was moreover curious that in most of the descriptions given of these engines Woolf's name was associated with them; and foreigners generally seemed to look upon Woolf as the originator of the double cylinder engine, which strictly he was not, although he revived its use, and thereby probably did a greater service than even the original inventor, because he brought into use what Hornblower had not succeeded in establishing.

Since the time of Woolf's revival of the double cylinder engine, so great an advance had been made in the construction of stronger boilers and the use of a higher pressure, and in the introduction of super-heating, that there was now a better prospect of extending the adoption of this engine, in which expansion could certainly be carried to a much greater extent than in a single cylinder, as shown in the paper. But there was still much to be done in respect of increasing the pressure of steam in stationary and marine engines, in which at present the common practice was to use only about 25 lbs. pressure per square inch, whereas in locomotives the pressure was frequently as high as 150 lbs., and would probably be carried higher. If this pressure could be attained in marine and stationary engines, great economy of fuel would result; but the greater expense required in the construction of the engine in the first instance was in most cases the obstacle in the way of any high degree of expansion; and even where an engine was provided with separate valves for working expansively, the expansion valves had been abandoned, and the full steam kept on through the entire stroke, involving a wasteful consumption of fuel. The papers that had been read would he thought do much towards advancing the general knowledge of the value and practicability of the double cylinder arrangement.

In pumping engines indeed, such as had been described, the slow and deliberate action, and the careful way in which such engines were generally attended to, afforded peculiar advantages for carrying out the application of the double cylinder engine; but there were other cases, especially marine engines, in which economy of fuel was evidently of far greater importance than in pumping engines, because the weight of fuel formed a limit to the load that could be carried: and to marine engines therefore the application of a high degree of expansion was particularly desirable. It was not necessary however to adhere closely to the arrangement of the double cylinders that was adopted for the pumping engines, which in many cases would be inconvenient, since it would necessitate either four cranks for two pair of cylinders, or else the use of a beam for each pair as in the pumping engines. In the marine engines shown in the Exhibition by Mr. Humphrys, similar to those working in the "Mooltan" with Hall's surface condensers, the small cylinder was mounted on the top of the large one and the same piston rod was carried through both cylinders, requiring some alteration in the arrangement of the passages to convey the steam from the small cylinder to the large one: but the short distance that the steam had here to travel from the bottom of the small cylinder to the top of the large one compensated for the long distance it had to travel from the top of the small to the bottom of the large cylinder, so that he believed there was altogether not much difference in loss of pressure in the steam passages between these engines and the double cylinder pumping engines shown in the present paper. There was also a small horizontal engine among the Belgian machinery in the Exhibition, designed for driving the gun-boats of the Swedish navy, which had a small cylinder placed within a large one, with three piston rods, one from the inner piston and the two others from the outer annular piston; the high pressure steam was admitted to the inner cylinder, whence it was conveyed to the outer low pressure cylinder by passages through the cylinder covers, with a considerable loss of pressure in the passages in this case on account of their length. In other respects the arrangement seemed good, and it was simple and well adapted for the purpose for which it was intended.

Mr. J. SCOTT RUSSELL said the introduction of a high degree of expansion in marine engines was greatly to be desired, but the difficulty attending it was the great strain thrown upon the machinery at the commencement of the stroke compared with the mean force of the entire stroke; and it was with the view of obviating this difficulty that he had himself designed some years ago the plan which had been mentioned of putting the small cylinder inside the large one and working with three piston rods, admitting the high pressure steam to the inner cylinder and expanding into the outer. There were however several inconveniences for the practical purposes of steam navigation in any of the combinations of cylinders that he had yet seen. Working with two cylinders was attended with certain trammels in the case of marine engines, which virtually limited the expansion to a particular grade; whereas the special want in steam navigation was the means of working with a great variety of grades of expansion, and sometimes with no expansion at all, but with the full power of both cylinders. When this difficulty was surmounted, the great practical inconvenience of double cylinder engines for marine purposes would be got rid of. Another difficulty in the way of extending the degree of expansion was the want of a better class of men to attend to the engines placed in vessels; until superior men were employed it would be unwise to attempt obtaining the large economy that would result from greater expansion, higher pressure, superheating, and surface condensation, with the use of more costly engines and stronger boilers. In order to get over the difficulty of repairs, arising from the complexity of a double cylinder engine, he had arranged an engine with three separate cylinders, all working expansively and acting direct upon one crank, so as to have the free use of any degree of expansion without the disadvantage of the double cylinder arrangement. With this engine, expanding the steam about four times in each of the three cylinders, the consumption of coal in ordinary working was brought down to about $2\frac{1}{2}$ lbs. and even 2 lbs. per horse power per hour. Marine engines however had not the same advantages for great expansion as pumping engines, in which the large mass to be put in motion absorbed the excess of power at the beginning of the stroke, and served as a reservoir of power to perform the remainder of the work when the high pressure of the steam was reduced by expansion.

Mr. E. E. ALLEN observed that the alleged difficulty of obtaining a temporary increase of power had been frequently urged against the use of double cylinder expansive engines for marine purposes, but he was not able to see how the objection applied, because the steam, instead of being cut off at a third or a half of the stroke or at any other point that was desired, might be kept on for the full length of stroke in the first cylinder, when the full power of the engine was wanted. In ordinary marine engines cutting off at three quarters of the stroke there was no means of adding to the power more than about one fifth; but if a larger and more expansive engine were used, with the steam cut off at one third of the stroke in the small cylinder, which was what was generally proposed in double cylinder expansive marine engines, the power could be increased between two and three times. An important difference moreover between the application of the double cylinder expansive arrangement to marine engines and to other purposes was that, while it was quite possible in pumping engines and in most other cases to lengthen the cylinders for an increased expansion, making the length of stroke frequently three or four times the diameter, it was impossible to do so in marine engines, which were confined within very narrow limits, so that the cylinders assumed a different shape from those in other engines; in marine engines of 1200 horse power now being made the diameter of the cylinder was more than double the length of stroke, the diameter being nearly 10 feet while the stroke was only 4 feet. In cylinders of these large diameters however, not only was the initial blow of the steam very much in excess of anything that was met with in pumping engines, but there was a heavy loss in the clearance space at the end of the cylinder, bearing a large proportion to the whole steam used if the steam were cut off at an early part of the stroke. The double cylinder engine had therefore a great advantage for short strokes, by reducing the initial blow with a high degree of expansion, and he believed it afforded the only practical mode of carrying out expansion to any high degree in marine engines. He had proposed placing the cylinders horizontal, with the small cylinder at the back of the large one, instead of the vertical arrangement adopted in the "Mooltan" and other vessels, because he objected to raising the engines, especially when the cylinders were large and heavy.

The degree of expansion and point of cut off to be adopted depended upon the pressure of steam employed: with an initial pressure of 20 lbs. per square inch above the atmosphere he had proposed that the steam should be expanded 7 times, and about 10 times for 60 lbs. total pressure, and perhaps 18 times for 120 lbs., the economy obtained being greater the higher the pressure of steam used. The expansion of 7 times was the same that had been adopted by Mr. Humphrys and Messrs. Randolph and Elder with 20 lbs. steam or 35 lbs. total pressure, the object being to expand the steam down to a final pressure of about $4\frac{1}{2}$ or 5 lbs. per square inch above a vacuum.

When expansion was fully carried out in marine engines there was reason to look forwards to the consumption of fuel being reduced to less than half what it now was. At present the average consumption reached $4\frac{1}{2}$ or 5 lbs. per indicated horse power per hour, but by expanding 7 times with 20 lbs. steam he believed this would be brought down to $2\frac{3}{4}$ lbs. per horse power per hour; and if surface condensation were employed in addition, the consumption would be further reduced to $2\frac{1}{4}$ lbs. of fuel, which was the actual consumption in the engines of the "Mooltan" during a continuous sea voyage, and also in Messrs. Randolph and Elder's engines.

Mr. E. A. COWPER did not consider it was necessary to adopt the plan that had been mentioned of having three cylinders in marine engines for obtaining a high degree of expansion; nor did he think the other plan of putting the small cylinder inside the large one was altogether advisable, as it involved certain complications of construction. In the latter case, although there were two cylinders, they could act only on one crank; and the outer annular piston would be subject to a great amount of wear, by being confined between the two cylinders, instead of being left as free as possible in working, which was particularly desirable in a marine engine. The use of two cylinders of different size with cranks at right angles had been tried several times, by Mr. Zander about fourteen years ago, by Mr. Rontgen about eleven years ago on the Rhine, and by himself twelve years ago, the steam expanding out of the small cylinder into the large one: this plan required a space between the two cylinders for the steam to expand into on leaving the small cylinder, because at the end of the

stroke of the small cylinder the crank of the large cylinder was at half stroke, and therefore not in the position for taking steam, so that a steam-jacketted reservoir was required into which the steam could be exhausted from the small cylinder, and in which it could be kept without any loss of heat and be slightly superheated before being admitted into the larger cylinder. In this particular arrangement he had found that a great advantage in uniformity of power was obtained by cutting off the steam at particular points near half stroke in both cylinders: it had been proposed many years ago to cut off the steam at half stroke, with the view of obtaining uniformity of rotative power; but the exact point of cut off had to be ascertained for each case, to produce the best result. The total variation from the average rotative power when the steam was admitted through the whole stroke in both cylinders was 31 per cent.; but when cutting off at the most advantageous point near half stroke in each cylinder it was only 14 per cent. This was shown in the diagram, Fig. 12, Plate 75, in which the curve L represented the rotative power obtained from one cylinder throughout one revolution of the crank, as measured by the height of the curve at successive points from the base line X, which represented the path of the crank; and the curve M represented the power obtained at the same time from the second cylinder, the steam being admitted throughout the whole stroke in each cylinder. The curve N gave the combined rotative power of the two cylinders at the successive points of the entire revolution, measured from the base line Y; and showed an extreme variation in the power of 31 per cent. from the average line P. The curves R and S showed similarly the rotative power when the steam was cut off at the most advantageous point near half stroke in both cylinders; and the curve T gave the combined rotative power of the two cylinders in that case, showing a variation of only 14 per cent. from the average line U, and thus giving a practical uniformity of effect. In the diagram the length of the connecting rod had been taken into account. In the case of using full steam throughout the whole stroke it had also to be observed that the variations in rotative power were not only large in amount but long continued; for instance in the first quarter of the revolution the power was greatly in excess of the average, but in the third quarter it was

greatly below the average, as shown by the curve N in the diagram. When cutting off however at the most advantageous point, each quarter of the revolution had nearly the same rotative power, as shown by the curve T. The amount of power not obtained from the steam, owing to the drop in the expansion curve at the point of exhausting into the reservoir from the small cylinder, when cutting off at nearly half stroke in both cylinders and expanding nearly nine times, was very small in amount, and formed an insignificant portion of the whole power, as shown by the combined indicator figures taken from the two cylinders, compared with the true expansion curve or such as would be given from a single cylinder having the whole expansion performed in it. This was the result that had been obtained with a 40 horse power horizontal engine constructed on this plan by Messrs. Walter May and Co., shown at the International Exhibition. The great uniformity of rotative power obtained, together with the great economy, would prove most important advantages in the case of cotton mills, flour mills, marine and pumping engines, and indeed manufactures generally.

Mr. T. HAWKSLEY remarked that from his own experience he believed that in pumping water the single cylinder rotative engine expanding the steam not more than three or four times, with a boiler pressure not exceeding 30 lbs. per square inch above the atmosphere, was for all ordinary purposes the best kind of engine that could be adopted. Such an engine did not indeed realise all the advantages which theory assigned to the double cylinder engine, and the power of the steam might undoubtedly be utilised to a greater extent by carrying the expansion further. But practically, whether as regarded the first cost of the engine or its durability or the facility of its management, he was convinced that a single cylinder engine, worked as he had mentioned, was as a general rule the best that could be applied to pumping purposes. Where the district to be supplied was generally flat, such as the east of London, and where the water could be delivered into a stand-pipe to one uniform height, he considered the single cylinder Cornish engine with loaded plunger was eligible for pumping. Also in raising water from a deep pit, which frequently had to be done for the supply of towns as well as in draining mines,

he had found the Cornish engine was again practically the best, because it worked under a uniform steady pressure without being exposed to fluctuations from any cause, and gave due time for the rods to come to rest; and this was a case in which the expansion could be carried somewhat further than three or four times. There were cases however in which it was desirable to use the double cylinder engine, and these formed probably the great majority of all the cases that occurred in waterworks: where the water had to be pumped either direct into the town or into a remote reservoir, and where consequently the water was taken off from the mains at intermediate and irregular intervals, producing a considerable variation in the amount of pressure; and also where the height to which the water had to be raised rendered a stand-pipe unavailable. Here it was found useful to apply a flywheel; and it was then also desirable to carry out the expansion to a considerable extent, as the steam could in practice be expanded further when a flywheel was used than in the Cornish engine without flywheel. It therefore became a consideration how best to get this increased amount of expansion; and the double cylinder engine was found, as shown in the first of the two papers that had just been read, to afford the means of so limiting the initial blow of the steam as that practically there was no necessity for employing a great weight of material to obtain the requisite strength in the engine, since the strain on all the machinery could be reduced to a minimum for a given power, by properly adjusting the proportions of the two cylinders and cutting off at the proper point of the stroke in the small cylinder.

In reference to the actual extent of expansion that could be realised, very high degrees of expansion were often spoken of, with corresponding economy of fuel; but he considered the expansive power of steam at ordinary pressures could not be realised beneficially beyond a limited extent, because the passive resistance in an engine of moderate size amounted practically to something like 5 lbs. per square inch on the piston. The back pressure from defective vacuum in the cylinder was rarely less than 2 lbs. per square inch in the best constructed engines: and the working friction of the engine under its load, even in engines of considerable size, was seldom below 3 lbs. per square inch on

the piston; sometimes it was rather less, but only in large engines. Hence there was no gain in carrying the expansion so far that the pressure of the steam should at any time be reduced to less than 5 lbs. per square inch above a perfect vacuum, since every portion of the stroke that was done with a pressure below 5 lbs. per square inch was done at a loss. Pumping engines for waterworks were generally worked with steam at about 30 lbs. per square inch above the atmosphere or 45 lbs. total pressure, and consequently the steam ought not to be expanded more than nine times under those circumstances. If therefore under such circumstances steam were expanded as much as fifteen times from the same initial pressure in the engines described in the paper, as had been stated, part of the expansion must have been performed at a loss.

It had also been stated that in one trial of the double cylinder pumping engines a duty was realised of about 130 millions of lbs. raised one foot high by 112 lbs. of coal, giving a consumption of about 1.7 lbs. per horse power per hour; but by the ordinary calculation that would require an expansion of forty times, and as it was clear this could not have been the case, he could only conclude there had been some mistake in the experiment, which might readily arise from a variety of causes. It might not be theoretically impracticable to get down the consumption of coal to 1.7 lbs. per horse power per hour, but he was convinced it was altogether impossible to do so under the practical circumstances in which steam engines were placed, either in pumping or on board ship or in driving machinery. He was acquainted with the double cylinder pumping engines described in the paper, which were certainly working with extraordinary economy, and he believed the discrepancy in the account of their consumption was sufficiently explained by the further statement that 37 per cent. of water had been lost out of the boilers beyond the consumption that corresponded with the volume and pressure of steam contained in the small cylinder at the point of cutting off. That extra quantity of water was no doubt carried over into the cylinder partly in the form of water mixed with the steam, and partly as steam leaking in through the valves after the cut off: for if the steam were not superheated on leaving the boiler, it was only by passing it through a large chamber

where it could deposit the water mixed with it before entering the cylinder that the actual expansion curve in the indicator diagram could be brought into conformity with the theoretical line; but when this provision was made, and when the valves were perfectly steam-tight, he had found the actual curve coincided as nearly as possible with the theoretical. He therefore believed the loss of water that had been stated fully explained the higher pressure which was shown in the indicator diagrams at the end of the stroke, above the final pressure that would have resulted from regular expansion.

In the use of high pressure steam its effect upon the materials of the engine was a subject that required some consideration. He had had an opportunity of watching the progressive change from low pressure to high pressure steam that had taken place during the last thirty years, and in one instance that had been under his observation a low pressure pumping engine erected and set to work in 1831 had still at the present time all its working parts and even the boilers nearly as perfect as at the time when it was put up; while on the other hand engines using high pressure steam of 30 lbs. and under, subsequently erected at the same place, had had the cast iron parts and many of the wrought iron parts completely cut through in the course of ten years. This could not be due as had been supposed to the quality of the tallow, for the same quality of tallow had been used in both cases; but he believed it was entirely due to a cutting or destructive action of the high pressure steam itself. This was therefore one of the causes of expense which would limit the use of high pressure steam in all cases where durability of the machinery was an important point.

In making a trial of any engines in order to ascertain the consumption of fuel, the condition of the boiler at the time ought not to be left out of the consideration. For if the boiler were thoroughly cleaned and the flues also cleared of soot, the evaporation might be increased in an experiment to the extent of 25 or 30 per cent. beyond what was obtained in the ordinary working condition of the boiler; and hence such experimental results could not be relied upon as any sure guide for what might be expected in regular practice. It was therefore important that in all statements of the quantity of water evaporated by a given consumption of fuel the condition of the boiler should be stated as well.

Mr. POLE remarked that, in reference to the extent of expansion that could be adopted with a given pressure of steam, there was no doubt a point beyond which no further advantage could be got from expansion, because the size of cylinder would have to be increased so much that the passive resistance of the engine would become so great as to overbalance the benefit of the expansion. But he thought this certainly could not be the case in expanding up to eight or nine times with steam of 30 lbs. per square inch above the atmosphere; and he believed that for practical purposes it was not intended to work the double cylinder engines to a greater extent of expansion with that pressure.

As regarded economy of fuel and the alleged impossibility of getting the consumption so low as 2 lbs. of coal per horse power per hour in regular practice, the reports of the Cornish engines showed that many of the best engines had been working regularly for years together with a duty of 90 millions of lbs. raised one foot high by one bushel or 94 lbs. of coal, which was equivalent to a consumption of 2 lbs. of coal per horse power per hour. The duty which had been stated to have been obtained in the trial of the double cylinder engines, 113 millions with 112 lbs. of coal, was also equivalent to the same consumption of 2 lbs. of coal per horse power per hour; and although this might seem an exceptional duty for the double cylinder engines, he believed it would not be found so, but that in regular working they would fall very little short of the best Cornish engines.

Mr. T. HAWKSLEY observed that the engines used in Cornwall, from which so high a duty had been obtained, were an exceptional class of engines; and even in these the duty at the present time had come down from the former amount of 90 millions to a duty now of only 56 millions on an average per bushel of coal. At the time when the engines were worked at the high duty of 90 millions, it was a common saying that a lb. of tallow was equal to a bushel of coal, and the engines all competing with one another got more than their proper allowance of tallow, so that the consumption of coal was diminished by the excessive lubrication. He was therefore satisfied that in engines of ordinary size and under ordinary circumstances it was a mistake to imagine that any such high results as had been spoken of could be

practically and economically realised in regular working, or even results within 50 per cent. of them.

Mr. POLE said it was certainly the case that the engines in Cornwall had receded from their former high duty, because when an engine was put up new it cost less in working than afterwards; and moreover as the workings in the mine were extended deeper, the engine had more work to do and the steam could not be expanded so much, so that less economy was then obtained.

Mr. J. SCOTT RUSSELL concurred in the importance of not carrying the expansion so far as that the pressure of the steam should ever be reduced below the passive resistance of the engine, in the case of marine engines and rotary engines generally where no flywheel was used; but in pumping engines with a heavy beam or flywheel he thought the limitation was not so applicable, because here the reservoir of momentum in the heavy mass in motion could be drawn upon for carrying the engine on to the end of the stroke even after the pressure of steam in the cylinder had been reduced below the resistance of the engine, when without the aid of that momentum the steam alone would be of no avail.

Mr. THOMSON said that, in reference to the annular construction of double cylinder engine that had been mentioned, he had last year made two pumping engines on that construction of 60 horse power each, and also a small double cylinder engine for a yacht which made from 300 to 330 revolutions per minute. In the latter instance the arrangement was modified by making the two pistons travel in opposite directions, in order that the engine might be balanced; and with the same object the centre piston was made heavier than in other engines, so as to be the same weight as the annular piston. The point of cut off in the small cylinder could also be varied from one quarter to three quarters of the stroke, and the expansion consequently altered between those limits. This engine had moreover a surface condenser, with a cold water pump to draw off the condensing water from it, worked at the same speed as the engine; but though the speed was so high there was no shake at all in the pipes of the pump.

With regard to the practical advantage of expanding the steam more than three or four times, and the amount of the passive

resistance of the engine, the indicator diagrams exhibited, as well as others that had frequently been taken from the double cylinder pumping engines shown in the drawings, gave a defective vacuum of only about 1 lb. per square inch; while the total dead resistance of the engine, including this defective vacuum, certainly did not amount to anything like 5 lbs. per square inch on the piston. He had also tried some experiments recently with several different degrees of expansion in one of the two 60 horse power pumping engines with annular cylinders that he had mentioned, in order to ascertain the degree to which the expansion could be advantageously carried in practice. For this purpose the evaporative duty of the boilers was entirely left out of the account, and the engine having injection condensers the quantity of injection water supplied was measured by a meter and thereby kept uniform: the load on the engine was also kept almost perfectly uniform, as the engine was employed in pumping water, and a counter was attached to ascertain that there was no variation in the speed of working; the work done by the engine was thus measured and maintained as uniform as possible. The expansion was then varied to different degrees whilst working, the initial pressure of the steam admitted to the cylinder being increased as the degree of expansion was increased, so as to keep the total power of the engine uniform throughout the experiment, to correspond with the uniform work to be done. The steam was first cut off at 7-10ths of the stroke in the small cylinder, giving an efficient expansion of 5.7 times, neglecting the expansion in the passages and clearances, since the larger or annular cylinder was four times the size of the small inner cylinder: and the temperature of the waste water in the hot well being measured was found to be 96° Fahr. The expansion was then increased by cutting off the steam 1-10th earlier in the stroke successively, and the following results were obtained:—

Point of Cut off in small cylinder.	Total Efficient Expansion.	Temperature of Water in hot well.
7-10ths of stroke	5.7 times	96 degrees Fahr.
6-10ths "	6.7 "	94½ "
5-10ths "	8.0 "	93½ "
4-10ths "	10.0 "	92 "
3-10ths "	13.3 "	91½ "
2-10ths "	20.0 "	91½ "

Hence it appeared that no improvement was effected by cutting off earlier than 3-10ths of the stroke, making the efficient expansion 13·3 times; for on increasing the expansion to 20 times with the cut off at 2-10ths of the stroke, the temperature of the waste water in the hot well was no further reduced, but remained the same as in cutting off at 3-10ths. In the temperatures obtained in these experiments the diminution indeed was certainly not so great as it ought to be by theory; for with a temperature of 96° when the steam was cut off at 7-10ths of the stroke, the diminution of temperature on cutting off at 3-10ths ought to have been something like $1\frac{1}{2}$ or $1\frac{3}{4}$ times what was actually found.

The CHAIRMAN suggested that the quantity of water lost from the boiler by priming and carried over with the steam into the engine would probably account for the higher temperature in the hot well, as well as for the increased pressure of steam at the end of the stroke. He enquired what was the initial pressure of the steam when it was expanded thirteen times.

Mr. THOMSON thought that all the heat which passed off from the engine must find its way into the condenser, and would there be shown by the temperature of the water in the hot well, which was therefore taken as the measure of the waste of heat accompanying each grade of expansion. No heat would pass into the condenser beyond that which remained in the steam at the end of the stroke after expansion, excepting of course a certain quantity of heat imparted from the steam jacket of the cylinder, which would be the same under all circumstances. The initial pressure of the steam at the time of expanding thirteen times was about 30 or 35 lbs. per square inch above the atmosphere, as shown by the indicator diagram: in ordinary working however the steam was cut off at half stroke in the small cylinder, which gave an expansion of eight times, the large cylinder being four times the size of the small one; or seven times efficient expansion, neglecting the passages and clearances.

Mr. T. HAWKSLEY considered the experiments that had been mentioned with different degrees of expansion did not furnish any proof that the higher expansions were not carried on at a loss; and he thought this would not be detected by the plan which had been

adopted of measuring the temperature in the hot well. For in an extreme case of a cylinder of excessive length, if the steam were cut off so early as to be expanded below the passive resistance of the engine long before the end of the stroke were reached, the latter part of the stroke would all be done at a loss, without the steam exerting any appreciable force on the piston; but still almost the same quantity of heat would be sent forwards into the hot well as if the stroke had been stopped at that point where the pressure of the expanded steam was just balanced by the passive resistance of the engine. It was therefore important to make sure in every case that none of the previously gained power should be afterwards wasted in merely overcoming the useless resistance.

Mr. E. E. ALLEN observed that with steam of 35 lbs. per square inch total pressure an expansion of seven times would reduce the pressure to 5 lbs. per square inch above a perfect vacuum, and he was not aware that it was ever proposed to expand further with that pressure of steam, certainly not in marine engines; since it was generally considered useless to reduce the final pressure below that amount, which usually covered the friction of the engine and the back pressure of the condenser; and therefore a higher expansion could be adopted only when a higher initial pressure of steam was used. It was accordingly impossible to fix any particular grade of expansion for all cases, but the expansion must always be proportional to the initial pressure of steam, so that with 55 lbs. total pressure the steam should be expanded ten or eleven times.

With regard to the consumption of fuel, he fully concurred in the opinion that, if the steam were only 35 lbs. per square inch total pressure, by no possible arrangement could the consumption be reduced to less than about 2 lbs. of coal per indicated horse power per hour, which was the limit even when surface condensation was adopted. But if greater economy were desired, the pressure of the steam must be raised; and then with 120 lbs. steam there would not be the slightest difficulty he believed, even in a marine engine, in reducing the consumption to about $1\frac{1}{2}$ lbs. of coal per indicated horse power per hour.

In reference to the particular form of engine best adapted for marine engines, the only objection that he knew of to the three cylinder arrangement, or the double cylinder with cranks at right angles, was the multiplication of connecting rods and piston rods; whereas by putting the small cylinder at the back of the large one, upon the same piston rod, only one connecting rod was required, and all the parts were reduced to the smallest size compatible with the initial pressure of the steam on the small piston and the pressure of the expanded steam on the large piston. If it were attempted to expand much in a marine engine with only a single cylinder of large size, such as 10 feet diameter, all the parts would have to be made strong enough to bear the full pressure of the steam on that large area at the beginning of the stroke; while for all the rest of the stroke the strength of the parts was much above what was needed. In the double cylinder arrangement however the high pressure steam admitted into the small cylinder was reduced by expansion to about a third of its initial pressure, before being let into the large cylinder, whereby the weight of the engine was reduced fully $2\frac{1}{2}$ cwts. per nominal horse power.

As regarded the back pressure of the imperfect vacuum, many experiments had been made on this point, and he believed that good marine engines would work regularly with a back pressure of about $2\frac{1}{2}$ lbs. per square inch; the friction of the engine also amounted to about $1\frac{1}{2}$ or 2 lbs. per square inch on the piston, as had been stated; and the total passive resistance of the engine was therefore about $4\frac{1}{2}$ lbs. per square inch, below which pressure the steam certainly could not be usefully expanded, whatever its initial pressure might be.

The CHAIRMAN proposed a vote of thanks to Mr. Pole and Mr. Thomson for their papers, which was passed.

The following paper, communicated through Mr. J. Scott Russell of London, was then read:—

ON THE CONSTRUCTION AND APPLICATION OF IRON ARMOUR FOR SHIPS OF WAR.

BY MR. NORMAN S. RUSSELL, OF LONDON.

The problem of forming an iron fleet would at first sight seem a simple matter; for starting with the following facts, proved by experiment—first, that 1 inch thickness of iron breaks up shells so as to prevent their explosion as shells; secondly, that $2\frac{1}{2}$ inches thickness of iron stops them completely, and prevents the fragments of the broken shell from being carried through the ship's side like grape; and thirdly, that $4\frac{1}{2}$ inches thickness stops the heaviest shot fired from the most powerful guns which the science and manufacturing skill of this country have hitherto produced—it is only necessary that the vessels of the present wooden fleet, as they already exist with engines on board, should be coated with the heaviest of these three thicknesses of iron which each ship is able to carry, and an iron-plated fleet will then be obtained. It is true that this immense fleet will cost more than a new and effective one of equal power; that not one of these vessels would be able to cross the Atlantic; that the entire fleet could not prevent a single fast cruiser from seizing all the gold ships on their way from Australia; and that they would not effectively blockade the coast of any foreign power with whom there might be war: our supremacy at sea would be gone, but we should be safe from invasion, and able to stop an enemy attempting to land here.

This problem has already been tested with regard to the iron-coated French and English batteries. Several of them were built by this country and sent on their way to the Crimea; but after several disasters, and going as fast as they could under steam and sail, they got only half way, and returned to this country having done nothing: in short they were not sea boats. Such an iron-plated wooden fleet

would be of a little more value than local batteries on shore, but only a very little; they could shift their position it is true, and provided it was known where an enemy intended to land, they could prevent his landing; but their advantage in this respect over land batteries would hardly compensate for their superior cost.

If it is desired to retain our supremacy at sea, a fleet must be formed that can not only fight a battle, but also ensure winning it. Such a fleet must be designed and constructed anew from the beginning; whether it shall be constructed entirely of iron or with wood backing to support the armour plates is still an open question; but in order to possess all the good qualities which are required in naval warfare, there can be no doubt that the structure of the vessels must be of iron. The real difficulty of the problem consists in this, that any existing ship of war when iron-coated will be slow, unseaworthy, and combustible, and will be incapable of long voyages; whereas the fleet of England must be able to keep at sea for a long time, to steam long distances, to go faster than the ships of any other country, and to be in better condition than other fighting vessels in all weather, especially the worst. The whole difficulty consists in designing vessels possessing all these qualities in addition to being shot-proof.

To begin the consideration of an iron shot-proof fleet, by taking an example of a vessel which it would be wished to construct if possible; the question arises, can shot-proof gun boats such as have hitherto been built be now built 140 feet long, 24 feet beam, of 80 horse power, and carrying 4 guns; and the answer is, they cannot be built, because the weight of iron would sink them. Even an iron-plated corvette of a favourite class, 190 feet long, 36 feet beam, and drawing 16 feet of water, propelled by 250 horse power engines, could not be constructed. In short, to carry a high side out of the water, the ship cannot be much less than 60 feet beam; and to go with the requisite speed it must have a length of about 400 feet; it would then be a completely shot-proof iron ship worthy of the British fleet, but even this vessel would be 7000 tons burden. Smaller vessels can of course be built, but if they are to have good qualities and are intended to act in concert with the more powerful vessels, they must be only partially coated and will be compromises.

The first ship of this class will be like the "Warrior," shown in Fig. 1, Plate 76; the next will be a smaller vessel with only the engines, boilers, and magazine protected; and the last will be a small shallow-water gun-boat, with one gun protected by a shield in front. But as far as a sea-going fleet is concerned, the engines, boilers, and magazine must be protected; and it is this indispensable requirement which makes an effective ship of war really a very large one. It seems to be agreed that 14 knots an hour is the minimum speed of fighting vessels of war for the future; but this speed cannot be got in a vessel under 200 feet long, and for that purpose the lines must be very fine. In order to carry the engines and boilers, which must be protected, the ship must be 60 feet longer; and in order to carry also a coated battery of 10 guns it will have to be 40 feet beam; and even then the vessel is only partially coated.

It will thus be seen that the large size of vessels which are to be entirely coated, and the mere partial coating of smaller vessels, are equally inevitable. Both are the results of unalterable laws, in the adoption of which there is no choice. This point has to be insisted upon the more strongly, because the question has sometimes been considered as if both the size of vessels and the extent and nature of their armour were matters of free choice. Such vessels are inevitably of enormous cost, and therefore too much pains cannot be bestowed on their mechanical design and the structure and durability of their armour.

The consideration of armour resolves itself into three principal questions:—first, what is the best kind of armour merely to resist the impact of shot; for which purpose the armour may be considered to be simply hung on the side of the ship, in no way contributing to the strength of the structure but merely as dead weight hanging on the hull. Secondly, what is the best way of forming the structure of a ship entirely of iron, with a view of employing the whole strength of the iron for the purpose of rendering the structure of the ship as strong as possible; making the vessel only so far shot-proof as the nature of the structure will admit, and considering resistance to shot a secondary object. In the first of these methods armour plates are hung on an already finished ship; in the second a ship is built up of

thin plates in such a way that these plates may afford as much protection as their weight can give. It remains to be considered however, thirdly, whether the thick armour plates and the thin ship plates could not be so combined together in the structure of a ship as to give that ship all the benefit of them both as armour plates and as integral parts of the strength of the ship.

The first of these questions is easily disposed of. In the original floating batteries of 1854 an ordinary wooden hull of a ship was covered with iron plates weighing about 3 tons each and 4 inches thick, tacked on by through bolts of $1\frac{1}{2}$ inch diameter, slightly coned and countersunk on the outside with nuts on the inside, perforating of course the sides of the vessel. It is in this simple and rude manner that the six vessels now building by the Admiralty are coated over, with $4\frac{1}{2}$ and $5\frac{1}{2}$ inch armour plates. The armour of the French wooden vessels is also fixed in this manner, except that wood-screws have been substituted for through bolts and nuts, as shown in Fig. 2, Plate 77, which represents a section of the armour of "La Gloire," the first constructed of the armour-plated ships.

The "Warrior," the first English armour-plated ship, is also coated on this principle, as shown in Fig. 3, which is not affected by the circumstance of this vessel having an iron skin.

The first reliable experiments made in this country on armour plates were those against the side of the "Trusty" in 1859, of which Admiral Halsted has left a valuable record. The armour, shown in Fig. 4, Plate 77, consisted of 4 inch iron plates fastened to the side of the vessel, which was equal in scantling to that of a 90 gun ship. The general result of these experiments was that out of more than 25 shots, fired from Armstrong, Whitworth, and ordinary 32 pounder guns, only two shots pierced the armour at the joints of the plates, and these were then so spent that they dropped on the deck of the ship without reaching the other side. It is not known that any experiments were made on the armour of "La Gloire"; no doubt the actual experience gained from the iron-coated floating batteries at Kinburn was considered of more value than any which could be obtained from firing against a target under circumstances that could scarcely occur in actual warfare.

The "Warrior" target, Fig. 3, Plate 77, like the plating of "La Gloire," was based upon the experience gained by the French floating batteries at Kinburn, and $\frac{1}{2}$ inch was added to the thickness of the plates as an allowance for the improvements in artillery, making $4\frac{1}{2}$ inches total thickness. The plates were wider, and the iron skin was placed behind, forming the side of the iron "Warrior." This target was subjected to the fire of the ordinary Armstrong and smooth bore guns; the plates were driven in from the bolt heads and were bent and buckled in a manner that proved their admirable qualities, but the bolts were not broken, except when struck by shot, and the skin remained intact. This was the great triumph of armour plating, which proved that the iron-coated ships then in existence were invulnerable under circumstances very unlikely to be reached in an actual naval battle. Subsequently experiments were tried with the 156 pounder gun, and the three shots fired at the target punched a clean hole through the armour plate, and lodged in the backing, but did not penetrate the iron skin behind.

In the second method of constructing iron war ships, the best structure of the ship exclusively has been kept in view, and it has been endeavoured by increasing the thickness of the structure to render it shot-proof, without sacrificing any of the materials for that purpose but retaining the use of their whole strength in the ship. This was a very likely course for either an engineer or a shipbuilder to follow, and those who took up the subject from a mechanical point of view have more naturally adopted this system, which may be called the structural system; while the artillerist took up the former plan of simple iron armour, neglecting structural considerations. The principal applications of this second system are shown in Figs. 5, 6, and 7, Plate 78.

Experiments on armour plates were made in the United States at the beginning of the present century by Mr. Stevens, the father of the present system of armour-plated ships; and the "Stevens Battery" shown in Fig. 5, Plate 78, was constructed at a later period by the American government in consequence of those experiments. The ship was only half finished when its construction was discontinued; but

since the agitation of this question in America several experiments have been tried to test the peculiarities in the construction of this vessel, by subjecting a target of similar construction to the fire of the heaviest American naval guns. This armour is $6\frac{3}{4}$ inches thick in all, being composed of a 2 inch plate with a number of $\frac{3}{8}$ inch plates behind it. The "Stevens Battery" like the "Warrior" is an iron ship, and between the iron skin and the armour there is a timber backing of 14 inches of locust timber. The target was placed on a slope of $27\frac{1}{2}^{\circ}$ to the horizon, and fired at from a distance of 220 yards by a 10 inch service gun weighing 88 cwts., and subsequently by a Parrot rifled gun of $6\frac{1}{2}$ inches bore weighing 86 cwts. The shot from the 10 inch service gun was solid spherical shot weighing 124 lbs., with a charge of 11 lbs. of powder. The deepest indentation made by this shot in the armour was $1\frac{3}{4}$ inch. Only 100 lbs. shells were fired from the Parrot gun, with 10 lbs. of powder, and they made an indentation only 1 inch deep. The slight effect produced upon the Stevens armour must be attributed to the great angle at which it was placed and the low velocity which 124 lbs. shot would have when fired with only 11 lbs. of powder. The Americans however still believe that a number of thin plates properly backed are better able to resist shot than one plate of equal thickness, which can only be considered to arise from an inability at present to forge or roll thick soft and homogeneous plates of large dimensions.

The armour of the "Merrimac," shown in Fig. 6, Plate 78, although it was designed simply for resisting shot, must necessarily from its peculiar formation add to the strength of the ship. It was not formed as is generally supposed of railway bars, but in a manner much more effective and ingenious. Bars of iron 6 inches wide and $1\frac{1}{2}$ inch thick were placed vertically on the side of the ship, and another outer layer of bars of the same width but $2\frac{1}{2}$ inches thick crossed the lower layer at right angles, the whole being bolted at each intersection to the side of the ship by $\frac{3}{4}$ inch bolts or screws. This armour seems to have stood remarkably well against the heaviest shot of the ships of war to which it was exposed, but fired at low velocities; for as far as it is known, no shot fired from the "Congress" or the "Monitor" pierced the side. It forms probably

the cheapest armour that can possibly be constructed, and has been introduced for fortifications by Captain Inglis, where weight is of no consequence and cost is everything. In the armour for ships of war however the case is precisely reversed.

In Fig. 7, Plate 78, is shown a section of the target constructed by Mr. Hawkshaw, who was one of the first to see the important advantages to be derived from the substitution of a structure of thin iron plates in place of the thick armour plate with wood backing, provided an equally effective resistance to shot could be obtained. This target consisted of twelve $\frac{3}{4}$ inch plates with a 2 inch plate on the outside, forming 11 inches thickness of iron altogether, the whole being rivetted together or tied by $1\frac{1}{4}$ inch screws tapped through all the plates at 8 inches pitch. Only a few shots were fired at the target, but the trial of it was a valuable experiment, and the result proved that future ships of war could not be formed of thin plates alone, though the question of iron backing still remained open.

Having now considered armour without strength and strength without armour, the third method of construction comprises the plans devised in the belief that nothing but thick armour plates perfectly solid can be shot-proof. In this conviction it has been attempted to connect the iron armour directly and immediately with the iron hull of a ship, so as to avoid wood backing with its rapid decay, its bad fastening and its bad structural qualities, and so as to make the entire hull and armour one homogeneous mass of iron, that it may as a whole possess vast strength and great durability. When this is done, the enormous cost of a fleet of large vessels will not be perilled by the chances of premature decay, and the ships will not be burdened by useless loads of material. Three plans have been tried for this purpose. One is that of the Iron Plate Committee who were to try the question of iron against wooden backing. A second plan adopted by Mr. Samuda may be called the thick plate structure, because it takes the thick plates of the armour and by scarfing them from the inside builds the upper part of the hull from the armour plates, so that they form the ship itself. The third plan by Mr. Scott Russell may be called the incorporation structure, because the hull of the ship is

here built up quite independent of the armour, and recesses are prepared in this structure into which the plates are let as into cells, and the edges of the cells are then rivetted down over the plates in such a manner as to incorporate the plates into the previously existing structure; by this plan the backing and fastening form parts of the ship, and the armour plates communicate as much strength as one uninterrupted rivet all round the edge can give them.

The Iron Plate Committee, knowing the advantages to be derived from the substitution of an iron for a wooden backing, designed the iron target shown in Fig. 8, Plate 78, which in every way except the wood backing was on the same principle as the "Warrior" target. The bolting was the same in principle, and there were ribs at the back; the only difference being that a little less material was put into the skin and a little more into the ribs. The result proved the utter insufficiency of the bolting, since 8 out of the 46 bolts holding on all the armour plates snapped off at the first round. It also proved that an iron target formed in this manner was not an improvement on the "Warrior" target so far as resisting shot was concerned. The target would probably have stood much better if the backing and framing had been exactly the same as in the "Warrior" and had had $2\frac{3}{4}$ inches of backing with 10 inch frames, instead of only 1 inch skin and ribs of twice that depth.

In Fig. 9, Plate 79, is shown the target next experimented upon, designed by Mr. Samuda. It differed from that of the Iron Plate Committee in having $5\frac{1}{4}$ inch plates, and having a very different system of framing; the chief peculiarity being a strong thick plate at the edges of the armour, through which the numerous $1\frac{1}{2}$ inch bolts or rivets were fastened. The framing of this target proved inferior to that of the previous one, but the plates curled up in a much less degree, and stood better, excepting at the edges where they were weakened by the bolt holes.

In Fig. 10, Plate 79, is shown the target next tried, constructed on Mr. Scott Russell's plan of continuous rivetting, wholly of iron, and introducing the principle of fastening the plates without bolts. The armour plates, of $4\frac{1}{2}$ inches thickness, are fitted in between wrought iron bars of the same depth which run longitudinally and

vertically along the ship's side and form part of its structure. These bars are heated at the outer edge and hammered down over the edges of the adjacent armour plates, in such a way as to form one continuous rivet passing all round the edge of each plate. There are several other plans for holding plates without bolts, which differ only in their practical execution from that now described, but their principle is the same, and the trial of this may be considered in effect as a trial of them all. The result of experiments proved that the fastening stood perfectly, and that an iron target could be constructed entirely of iron which could prevent the 156 lbs. shot fired with 50 lbs. of powder from passing through the armour.

Having now examined the effect of the shot upon all these different systems of armour plating, the writer would submit the following conclusions. In the first place a thick plate must be employed on the outside of the target. As much of the armour as practicable should be put into the structure of the ship, but it must have a thick plate on the outside. The plate must not only be a thick one, but it must also be a wide one ; in other words the fewer cracks in the armour to begin with the better. The large plates are of course very expensive, and it would be highly satisfactory if smaller ones could be made to do as well ; but the 68 lbs. shot insists upon large armour plates if it is to be kept outside the ship.

The next fact, which is common to armour backed with wood and armour backed with iron, is that every bolt hole weakens the plate. A large bolt hole does not weaken it more than a small one ; and if bolting is found to be the best mode of fastening, the bolts should be large and there should be few of them. The holding of the plate is of more consequence in an iron than in a wooden target, for this reason ; that the iron plate is driven bodily into the wood and the only purpose which the fixing serves is to keep the plate from absolutely falling off. It would prove a very instructive experiment and would not cost much to have the "Warrior" itself subjected to the same test as its section at Shoeburyness, and then sent to sea to try the effect of the rolling of the ship upon the loosened plates ; the dockyards would

also have an opportunity of finding out the easiest and most efficient method of repairing such an iron fleet.

It seems very remarkable that in the construction of armour plating such different mechanical proportions should have been adopted from those of other iron constructions, and that while 1 inch plates would be fastened together with $1\frac{1}{4}$ inch rivets or bolts, a large plate 20 feet long, upwards of 3 feet wide, and weighing more than 5 tons, should be fastened on by only fifteen 2 inch bolts. Mr. Samuda's target was far less injured and far less changed in general shape than that of the Iron Plate Committee, for the simple reason that there were a larger number of bolts to hold the plate to the skin; but they were unfortunately so close together that a couple of shots happening to strike the edges of the plates where they were weakened by the holes, one of the shots went clean through. In Mr. Scott Russell's target, constructed on the principle of fastening without bolts, the face of the target was less disturbed. The area of fastening or bolting to a given plate on this principle is 12 times that of Mr. Samuda's and 25 times that of the Iron Plate Committee's target.

The effect of shot on a target having wooden backing is to expend all its force on the armour plate, which is twisted and bent and curled up at the edges, but the iron skin remains intact. In the iron target, on the other hand, the skin and backing divide the work with the armour plate, and while the skin is broken through, the armour plate remains but little injured; and probably, although several shots did go through the two iron targets, if the firing were continued on them as well as on the "Warrior" target, the latter would be smashed in long before either of the former.

Whenever therefore ships come to be built entirely of iron, as will be the case at some future time if not now, it is submitted that they must have the following qualities: the armour plates must be wide, there must be no bolts, the fastenings must be large, and there must be an inner skin to prevent the pieces of iron from flying among the crew. Such an armour will then be superior in resisting power to that of the "Warrior," adding to the strength of the ship instead of detracting from it, having a skin uninjured and independent of the armour; and it will cost nothing for repair, but will last for ever.

It is important to glance at the power of shot fired at high velocities to penetrate iron armour, and the capabilities of the iron armour for resisting solid shot. Not much is known positively respecting this, but the following facts are tolerably well ascertained : that the 110 lbs. Armstrong shot has a velocity of 1200 feet per second, the 68 lbs. a velocity of 1580 feet per second, and the 156 lbs. a velocity of 1700 feet per second ; and that these shots have respective penetrating powers of 158, 170, and 430. It is also believed that, while the penetrating power of shot is as the square of its velocity, the resisting power of a plate is as the square of its thickness. This has not been absolutely proved by experiment, but is probably not far from the truth, and any error is due to the difficulty of manufacturing thick plates as homogeneous as thin ones. Assuming then the two following data, that the 68 lbs. shot just does not pierce a 4 inch plate, and that the 156 lbs. shot just does not pierce a $4\frac{1}{2}$ inch plate backed by 3 inches of iron, it can be determined approximately what thickness of plate and backing would be required to stop a given shot having a given velocity, and what size of vessel would be needed to carry such armour and also to possess all the qualities necessary in a ship of war. At present the shot fired from the most powerful gun yet made is stopped by a $4\frac{1}{2}$ inch armour plate and 3 inches backing of iron, and the vessel necessary to carry such armour is of 7200 tons burden, and has a displacement of 10500 tons, a saving in weight of 600 tons being here made by the adoption of the iron backing.

Although however no shot has penetrated the strongest armour hitherto made, guns will doubtless be made to pierce it, for an Armstrong gun is now being manufactured to throw a 300 lbs. spherical shot, and guns will probably be made to throw 400 and 500 lbs. shots. On the other hand, although 4 inch armour is no longer invulnerable, it must not be considered that the thickness of armour cannot be increased because a vessel could not carry the additional weight ; and the writer wishes to show that when the more powerful guns are manufactured and used in large numbers not only can the shot be stopped by armour of reasonable dimensions, but this armour can be carried by vessels of such moderate dimensions as to offer a fair prospect of the race between armour and artillery being

continued for the next twenty or thirty years. Thus taking the gun now in progress for throwing a 300 lbs. spherical shot, which may be assumed to have a velocity of 2000 feet per second at a range of 200 yards, this shot may according to the preceding data, be stopped by a plate 7 inches thick and backed by $4\frac{1}{2}$ inches of iron, as shown in Fig. 11, Plate 79. The minimum vessel required to carry such armour from end to end would be of 12000 tons burden and would be propelled by engines of 2000 horse power at a speed of 15 knots per hour; 1500 tons weight would be saved in the construction by the use of iron instead of wooden backing. Assuming still further that a gun is made to throw a spherical shot weighing 500 lbs. having a velocity of 2500 feet per second, such a shot could on the same data be stopped by

*Table of Dimensions of Vessels
to carry different thicknesses of Armour.*

	4½ inch Armour.	7 inch Armour.	11 inch Armour.
Length of Vessel	400 feet	500 feet	600 feet
Breadth	60 feet	70 feet	80 feet
Tonnage	7200 tons	12000 tons	20000 tons
Horse Power of Engines	1800 h.p.	2000 h.p.	3000 h.p.
Weight of Engines . . .	1800 tons	2000 tons	3000 tons
" Armour	2000 "	4300 "	10000 "
" Hull	2000 "	3700 "	5000 "
" Coals	4000 "	5000 "	7500 "
" Armament . . .	700 "	1000 "	1500 "
Total displacement . .	<u>10500 tons</u>	<u>16000 tons</u>	<u>27000 tons</u>
Weight saved by adoption of iron backing . }	600 tons	1500 tons	4000 tons

11 inch armour plates backed by 8 inches of iron, as shown in Fig. 12, Plate 79; and this armour could be carried from end to end by a vessel of 20000 tons burden and 3000 horse power, which would be under the size already attained in the Great Eastern. A comparative calculation of these vessels is given in the accompanying table.

It must be borne in mind that these vessels are coated from end to end; and smaller vessels can be made, but they must be only partially coated with these heavy plates. It will thus be seen that the days of armour-plated ships do not end with $4\frac{1}{2}$ inch armour, but that there will always be a race between armour and artillery: defence has up to the present time had rather the best of it, but that will not last long. It is only to be hoped that it may long remain a friendly race between artillerists and constructors of armour.

Mr. W. POLK thought the paper that had been read gave a fair account of what had hitherto been done in the construction of iron armour for ships. As a member of the Iron Plate Committee he would explain that the reason why the Committee's target was not made with precisely the same backing as the "Warrior" target was that it was wished to try some modification in the backing, but without adding to the weight of the target, which was intended to be in other respects as much like the "Warrior" target as it could be made.

The quality of the iron of which the armour plates were to be made was a subject requiring particular attention, and the first impression was generally that the plates should be hard, and even steel-clad ships had been proposed. This was however entirely a mistake; for the results of a large number of experiments tried by the Committee with iron and steel plates of all qualities proved most decisively that, instead of being hard, the proper material for armour plates was that which was as soft and as tough as possible. Hardness, whether in

steel or iron, was quite out of the question. Steel plates had been tried, and they proved the worst that could be used for such a purpose; they broke up under the blow of the shot and became entirely useless: semi-steel was slightly less objectionable, and hard iron was the next in order. The evil was that all hard material cracked, whereas soft material bent about and became indented without cracking; and for securing a safe protection the object was to get plates that would bend without cracking. If the plates cracked, two or three shots would make them crack in different directions, so that pieces of the plates would fall off, and therefore a crack was the worst result that could be obtained. Accordingly the best kind of plate for armour was that which was as soft and tough as possible, and toughness generally appeared to go with softness. The best descriptions of iron had been tried, and when they were soft they answered very well; but even expensive qualities of iron, if not soft, would not do, because it was softness that was indispensable. Hence an important result arrived at was that expensive qualities of iron were not necessary for armour plates, for it was possible to get iron of very reasonable cost which possessed the quality of softness sufficiently for this purpose, and the great object in making armour plates was now to use iron as soft as could be got.

With regard to the thickness of the armour plates, a general hope had been entertained prior to actual trial that the plan of building up the required thickness of iron by means of a number of thin plates bolted or rivetted together would prove successful, in place of a single plate having to be made of very great thickness. In this construction of armour the proper fastening together of the plates was a point of the greatest importance; and accordingly in the target constructed on this plan, as described in the paper, the fastening was very carefully attended to: the holes were not merely punched and the rivets driven in, but they were drilled with great care by Messrs. Cochrane in the same manner as the plates of the girders made by them for the Charing Cross railway bridge; and screwed bolts tapped through all the plates were also tried. The principle of thin plates was thus tried in its best form up to a total thickness of 10 and 14 inches; but when the target came to be fired at, the result left no doubt that this plan of

construction was a failure, and that the outside plate at any rate must be a thick one and of a soft quality. The reason appeared to be that the strength of a plate to resist the blow of a shot was something like the transverse strength of a beam supporting a weight, the strength being in proportion to the square of the depth of the beam or thickness of the plate, so that a single solid plate of great thickness possessed far more resisting power than a number of thin plates making up the same aggregate thickness of metal. The size of the armour plates should be made as large as possible, in order that the extent of edges might bear the least possible proportion to the area of the plates, because if the shot struck the edges or corners of a plate they were pretty sure to break off, but if it struck in the body of the plate, away from the edge, the iron had a better chance of resisting the blow without being damaged.

A good deal of enquiry had been made as to the best method of fastening on the armour plates, whether by bolting them on or by some other plan. In the Iron Plate Committee's target the bolts soon gave way, and several plans had been tried for doing away with bolts, among which was Mr. Scott Russell's ingenious method of holding in the armour plate by a sort of continuous rivetting all round the edge, like the fastening of a picture in a frame, by means of iron ribs projecting from the backing; the plate was then put in, and the edges of the ribs rivetted over. This plan of fastening the plates had proved thoroughly successful, though it was a more expensive method; and bolting was certainly the simplest mode of fastening, but if bolts were used they must be of large size for holding on plates of so great thickness. For joining the plates to one another, the plan of grooving and tonguing was adopted in the "Warrior", because it was thought that one plate would assist the other in receiving a blow at the joint. That however was found not to be the case, for instead of one plate assisting the other, when one plate was struck it broke the other, and therefore the plates were now simply made to butt together at the joints.

As regarded the question of wood or iron backing, the general impression after all the trials was that in reality the wood backing was very useful. There had been a desire to get rid of wood backing, and trials of iron backing had been made for that purpose; but the

iron backing of the Committee's target did not prove successful, and though that in Mr. Samuda's and Mr. Scott Russell's targets had succeeded better, it was still doubtful whether there was sufficient warrant for the exclusion of wood. The wood backing appeared to answer several useful purposes: for when the plate was broken by a shot, the wood backing entirely stopped the pieces which would otherwise fly into the ship in fragments; these got imbedded in the wood and could not go further. Moreover when a shot struck a plate, if it broke the plate it generally broke out a piece in a conical form, thus extending the fracture over a much larger area at the back of the plate, so that the blow was spread over a large surface of the wood backing, which had thus a better chance of stopping the broken piece of the plate, and still preserved the inner iron skin and the ribs of the vessel free from injury. The wood backing thus rendered important service in protecting the vessel, and, even though the armour plate might be broken, the broken pieces remaining in their place imbedded in the wood still offered some resistance to a second shot striking the same spot. The object was to keep out shot and shell, and if the broken pieces were not kept in their place by the backing, the shot and shell could enter at the fractured part of the armour plate. Another advantage of the wood backing was that it acted as a buffer or cushion to prevent the jar when the armour plate was struck by a shot from extending to the fastenings of the plate. The first thing noticed in the targets with iron backing when they were fired at was the enormous vibration or jar produced by the blow, which broke out the fastenings at a great distance from the spot struck, even as far as 11 feet. The wood backing however effectually stopped the jar, and it was found that in the immediate neighbourhood of the part struck the fastenings behind were scarcely disturbed at all. He thought there was no other mode of preventing the jar and getting the required elasticity than by the use of wood, for no other material would be sufficiently strong. Springs were entirely out of the question, owing to their weakness and the excessive force that would be brought against them. Even the wood must be as hard a quality as possible, and teak was the only wood that was used for the purpose: any of the softer kinds of wood would be totally useless. A further effect of the wood backing was

that, owing to its great thickness, it distributed the force of the blow of a shot over a large extent of surface behind, whereby the injury done to the ship's side was much less than if the effect were made local by the force being confined to the spot struck. These properties of wood backing certainly appeared to give it so great an advantage that hitherto scarcely any one who had witnessed the experiments had seen reason for doing away with wood, however desirable such a step might seem from other considerations.

Mr. T. W. PLUM enquired whether in Mr. Scott Russell's plan of fixing the armour plates in a frame any damage sustained in action could be repaired with facility ; and what was the thickness of the ribs or rivetting pieces in the waist or narrowest part, and whether the edges of the ribs were rivetted over cold in fixing the armour plates.

Mr. N. S. RUSSELL replied that the thickness of the ribs in the narrowest part was about 2 inches ; it might be made considerably thicker if necessary, but that had not been found requisite. The rivetting was done hot, the edges of the ribs being simply heated by portable fires and then rivetted down over the edges of the armour plates by hand hammers.

Mr. C. P. B. SHELLEY asked how the vertical joints were made between the armour plates in this mode of fixing.

Mr. N. S. RUSSELL explained that the vertical joints were made exactly the same as the longitudinal ones, by ribs of the same size with the edges rivetted over.

Mr. E. A. COWPER thought that in the targets in which the armour plates had been fixed by bolts to iron targets the bolts had not been applied in the best manner for holding the plates securely. In one target he had noticed that there were only a few 2 inch bolts to fix the armour plates, which were manifestly quite insufficient for the purpose, as he had pointed out previous to the experiment ; and at the first shot eleven bolts were broken, and the plates became detached : in this case the sectional area of the bolts amounted to only 1-37th of the area of the plates held by them. As a more secure mode of holding the armour plates he had suggested the plan of fixing them by means of strong square-threaded screws of 5 or 6 inches diameter, screwed in at the corners and along the joints of the plates at about

15 inches pitch, each screw thus holding two adjacent plates, which would bind the plates together more strongly than any feather or tongued joint: this plan was he expected about to be practically tried on the floating battery at Portsmouth.

Mr. J. RAMSBOTTOM enquired whether any experiments had been made with timber placed outside the armour plates, in order to diminish the blow of the shot upon the plates and prevent them from being broken. He thought 20 or 24 inches thickness of timber placed outside the plates, as thick as the timber backing in the "Warrior," might possibly have a beneficial effect in reducing the force of the blow on the plate.

Mr. W. POLE said one experiment had been tried with a few inches thickness of elm placed in front of the target, which had some slight effect in reducing the damage done to the armour plate, but not much; and it had also been proposed to put a considerable thickness of timber, as now suggested, in front of the armour plates, with a thin plate of iron again outside that to form an iron skin, but this plan had not yet been tried. It must be borne in mind however that the shot fired from a gun had a certain definite amount of power in it, received from the explosion of the gunpowder, the shot itself indeed being merely the means of conveying that power from the powder to the object struck. This definite amount of power or work contained in the shot must therefore be expended in some way or other upon the target or the ship's side, since no contrivance whatever could prevent it from being expended. It was as impossible to get rid of the power contained in the shot as it was to get rid of matter, and therefore it was a mistake to suppose that by the use of hard steel plates the effect of the blow could be annihilated altogether. Hence the object to be aimed at was not to get rid of the blow, but to receive it in the most harmless manner: and this was best accomplished by using a plate of soft iron which would admit of being knocked about and bent and indented without being actually fractured, instead of a hard plate offering an unyielding resistance, upon which therefore the work must be expended in actually breaking up the plate. It was on this account that a soft and tough quality of iron had so great an advantage for armour plates over a harder and more brittle metal. If a small

resistance were placed in front of the armour plates, by the interposition of a thickness of timber, that small resistance had of course to be overcome first by the shot, but the remainder of the power in the shot had still to be expended on the plates. An external layer of timber would also have the disadvantage of affording a lodgment for shell, and of being liable to be set on fire.

Mr. J. SCOTT RUSSELL thought the explanation given by Mr. Pole of the respective merits of iron and wood backing for armour plates was a very fair statement of their relative advantages. Though himself strongly in favour of wood backing, he was nevertheless fully alive to its faults, the principal of which were the great tendency of the wood to unknown decay at uncertain periods, the difficulty of obtaining a good fastening for the armour plates, and the fact that the wood backing was a mere dead weight to be carried by the vessel, which certainly materially affected the strength of the ship. He was therefore one of those who desired to see the timber backing done away with, on account of its perishable nature and its uselessness in reference to the strength of an iron ship; and to get instead a backing incorporated with the structure of the ship, and thereby adding to its strength. The trials of the various experimental targets had been a great help in this direction, and had resulted in putting iron backing very much more nearly on a par with wood backing. As it was found that holes and bolts through the armour plates were objectionable, a trial had been made of a target having as few of them as possible; but the result showed that there was then too little fastening for the armour plates, and the amount of fastening was therefore increased, with decided advantage to the plates.

An important step was also gained by the trials of the target composed of a number of thin plates rivetted together, because it had previously been hoped that by some plan of that sort a combination of thin plates could be made which would effectually resist the heaviest shot. In this trial however the shot went clean through the whole of the twelve $\frac{3}{4}$ inch plates composing the target, showing that no armour would do unless made in a single thickness of metal. The $4\frac{1}{2}$ inch armour plates were accordingly what had now been arrived at, with as great a thickness of timber or iron backing as the ship could carry.

In addition to the iron backing which he had proposed in place of the timber backing, it was intended to have also a separate iron skin, placed at 18 inches distance at least inside the armour plates; because it was necessary not merely to make the outside of the ship as strong as possible, but also to protect the men inside against pieces flying, which was done as effectually by this means when the iron backing was used as with the much greater thickness of timber backing. If it were conceded therefore that iron backing was now nearly on a par with the wood backing in protecting a ship, which he believed to be the case, it was of the greatest importance that further endeavours should be made to turn the scale in favour of iron backing; because if this could be accomplished, the adoption of iron backing would be a great advantage in strengthening the structure of the ship, and only 2 inches thickness of iron backing would be required to replace every 18 inches of timber backing. The target already tried with iron backing was practically shot-proof against the ordinary 68 lbs. shot, and against all except the heaviest guns, which it had not been intended to resist. It did indeed prevent even the 300 lbs. shot from actually passing through the armour; but the shot did so much mischief that a battery of 300 pounder guns would soon make a hole in such a ship's side. There was no doubt that the contest between armour plates and guns would long go on as it had done at present, with the advantage alternately on the one side for a time and then on the other: so that no construction of armour that could be devised would long remain shot-proof against the continually increasing power of the guns brought to bear against it.

In his own plan of fixing the armour plates on the ship's side, by means of continuous projecting ribs with the edges rivetted over the armour plates, the fastening of the plates was now rendered so secure that it would hold them in place until they were absolutely knocked to pieces by the shot; and this was the most that could be required of any mode of fastening. With regard to repairs in this mode of construction, it certainly was not so easy to take out a damaged armour plate when fastened in this way as it was to take off one of the ordinary bolted plates; it had indeed been purposely made as difficult as possible to get out one of the plates when once put in its place;

for it was better to put in the plates in such a manner that they could not be got out by any means than to put them in so that they could be easily knocked out, for the sake of being easily replaced after they had been knocked out. If this secure method of fastening the plates enabled a ship to fight a hard battle safely and win it, there could be small ground for complaint that it was hard to get the broken plates out in order to put new ones in for the subsequent repairs.

Mr. N. S. RUSSELL observed that although the repairs would certainly be more troublesome and expensive when the plates were fixed by the new plan of continuous rivetting, it was not impossible to repair them; but the question of repair was a secondary consideration, and in the case of the "Warrior" target the plan of dovetailing the plates into one another had been adopted, in spite of the difficulty thereby occasioned of removing a damaged plate at the water's edge, which could not be taken out without removing all the layers of plates above. The plan that had been suggested of fastening the plates by large screws inserted along the joints appeared to be the same in principle he thought as the other plans for fastening without the use of through bolts in the centre of the plates; and independently of the practical difficulty of cutting a thread of 6 inches diameter by hand in a ship's side, the area of fastening in this plan amounted to only about 16 square inches section of bolt for every 15 inches length of joint when the screws were placed at 15 inches pitch; whereas in the plates held by continuous rivetting the holding area along the edges was 84 square inches for every 15 inches length, the edge of the projecting ribs being rivetted down so as to cover more than one inch width of the edge of the plates.

Mr. E. J. REED thought that in the present transitional state of the question between armour plates and guns there could not be much objection to a few wooden ships being built at the present time for the fleet, which would be perfectly good for fighting for the next few years; and then when this rivalry had gone on through that time the ultimate construction of ship might be introduced, of whatever character it might be. In designing an iron ship he would be quite prepared to sacrifice some of the resisting power obtained by the present armour plates and timber backing, for the sake of securing

the great structural strength given to the vessel by Mr. Scott Russell's plan of armour with iron backing. Hitherto however he did not think any vast change was called for in the construction of armour-plated ships: for one of the ordinary 50 gun frigates could now be made perfectly secure by means of armour plates $4\frac{1}{2}$ inches thick extending down below the water line, backed by about 3 feet of solid timber, and provided with a battery of twelve of the heaviest guns that had been produced during the last year; this battery could be secured not only by the external armour on the sides of the vessel, but also by similar armour on the transverse bulkheads. The frigate thus equipped would he believed be a perfect sea-going ship, which could go out as securely as the "Warrior" or any other iron-plated ship, the only penalty incurred by the additional weight carried being about 15 inches extra draught of water and half a knot per hour less speed: and he had no doubt that the other wooden ships already existing in the fleet could in the same manner be made thoroughly efficient for fighting actions, by carrying a few very heavy guns fully protected instead of a large number of unprotected guns.

With regard to the quality of the iron of which the armour plates were made, he had observed that where the iron was of a superior quality the cracks produced by the shot were less than where the quality was inferior: and a plate of hammered iron from the Thames Iron Works, tried at Portsmouth, had several 68 lbs. shots sticking in it as they would do in any soft material like putty, and the iron was not starred with cracks at the places struck. In other plates also from the same works it was found that the cracks made by the shot did not as a rule go to the bolt holes, even where they went round and in the neighbourhood of the holes; and wherever a crack did happen to go to a bolt hole, it almost invariably stopped there. This fact could not be taken as in favour of bolt holes in preference to some other mode of fixing without holes through the armour plates, but it showed at any rate that the bolting sometimes did no serious mischief to the strength of the plates. At present the question of the method of fixing appeared to lie between the plan of through bolts and that of continuous rivetting; and he did not think a better plan could be found than the latter, if it were decided to do away with bolts altogether.

The CHAIRMAN concurred in thinking that in the present state of uncertainty with regard to armour-plated ships the best thing to be done was to make use of the wooden ships already existing, by coating them with armour plates. In the "Warrior" target he thought very much of the strength was to be attributed to the inner iron skin and the vertical ribs forming the framing of the target, without which its resisting power would be greatly diminished. For the strain produced by the blow of a shot diverged in a conical direction from the point struck; and in the "Warrior" target the $4\frac{1}{2}$ inch armour plate was backed by about 20 inches of teak, with two layers of iron behind of $1\frac{1}{2}$ inch thickness together, all of which was supported at short intervals by strong beams of double angle iron, corresponding with the vertical ribs of a ship: so that a blow struck at any spot on the armour plate was distributed over a large area at the back, and the effect was received by a large extent of the strong angle iron framing. Accordingly up to the present time no target had been produced which had as great resisting power as the "Warrior" target constructed in this manner.

He proposed a vote of thanks to Mr. Russell for the paper, which was passed.

The CHAIRMAN moved a vote of thanks, which was passed, to the Local Committee and the Honorary Local Secretary, Mr. Charles Cubitt, for the excellent arrangements they had made for the meeting of the Institution in London, and the handsome reception they had given to the Members on the occasion.

He also proposed a vote of thanks, which was passed, to the Council of the Royal Institution, for their kindness in granting the use of the Lecture Theatre for the purposes of the meeting.

The Meeting then terminated. In the evening the Members and their friends were entertained by the Local Committee at a *Conversazione* held in the Egyptian Hall at the Mansion House, by the kind permission of the Lord Mayor, where a collection of machinery, engineering models and drawings, specimens of manufactures, microscopes, &c., was exhibited.

On Friday, 4th July, an Excursion of the Members took place to the Royal Gun Factory and Arsenal at Woolwich, where through the special arrangements kindly made by Mr. Anderson they were enabled to witness the several processes of the manufacture and proving of guns and the other operations carried on at the Arsenal.

In the evening the Members and their friends dined together at the Crystal Palace, Sydenham.

PROCEEDINGS.

6 NOVEMBER, 1862.

The GENERAL MEETING of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Thursday, 6th November, 1862; CHARLES F. BEYER, Esq., in the Chair.

The Minutes of the last Meeting were read and confirmed.

The CHAIRMAN announced that the President, Vice-Presidents, and five members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Annual Meeting.

The following Members were nominated by the meeting for the election at the Annual Meeting : —

PRESIDENT.

ROBERT NAPIER, Glasgow.

VICE-PRESIDENTS.

(Six of the number to be elected.)

CHARLES F. BEYER,	. . . .	Manchester.
ALEXANDER B. COCHRANE,	. . . .	Dudley.
EDWARD A. COWPER,	. . . .	London.
JAMES FENTON,	. . . .	Low Moor.
BENJAMIN FOTHERGILL,	. . . .	London.
THOMAS HAWKSLEY,	. . . .	London.
ROBERT HAWTHORN,	. . . .	Newcastle-on-Tyne.
SAMPSON LLOYD,	. . . .	Wednesbury.
HENRY MAUDSLAY,	. . . .	London.
JOHN RAMSBOTTOM,	. . . .	Crewe.
C. WILLIAM SIEMENS,	. . . .	London.

COUNCIL.

(Five of the number to be elected.)

FREDERICK J. BRAMWELL,	London.
DANIEL K. CLARK,	London.
WILLIAM CLAY,	Liverpool.
JOHN FERNIE,	Derby.
SIR CHARLES FOX,	London.
THOMAS GREENWOOD,	Leeds.
GILBERT HAMILTON,	Birmingham.
EDWARD HUMPHRYS,	London.
JAMES KITSON,	Leeds.
JOHN VERNON,	Liverpool.

The CHAIRMAN gave notice that it was proposed by the Council to move a resolution at the ensuing Annual Meeting :—"That all Members who have filled the office of President of the Institution be ex officio permanent Members of Council, under the title of Past Presidents."

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected :—

MEMBERS.

JOSEPH BARROW,	Leeds.
EDWARD BARTON,	Sheffield.
HENRY WOLLASTON BLAKE,	London.
ALFRED BLYTH,	London.
JOSHUA FIELD,	London.
DOUGLAS GALTON, R.E.,	London.
THOMAS JOHN HAYNES,	Cadiz.
WILLIAM EDWARD NEWTON,	London.
ALFRED STANSFIELD RAKE,	Derby.
ROBERT RICHARDSON,	London.
JOSEPH F. STRONG,	Allahabad.
RICHARD TAYLOR,	London.

HONORARY MEMBER.

WILLIAM WHITEHEAD,	Sheffield.
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The following paper was then read :—

ON A PACKING FOR PISTONS OF STEAM ENGINES AND PUMPS.

BY MR. GEORGE M. MILLER, OF DUBLIN.

This Packing consists of two rings, pressed outwards against the cylinder by the pressure of the steam as it acts on the alternate faces of the piston, without the use of any springs. The construction of the piston is shown in Figs. 1, 2, and 3, Plate 80, as used by the writer in the Locomotive Engines on the Great Southern and Western Railway of Ireland. The piston is of cast iron, 2 inches in thickness and 15 inches diameter. Two square grooves A A are turned in the edge of the piston, $\frac{3}{8}$ inch in width and $\frac{3}{8}$ inch apart, and a corresponding steel ring is fitted into each groove, the rings being divided at one part with a plain butt joint, and sprung over the piston into their places. Two small holes B B, $\frac{1}{8}$ inch diameter, open from each face of the piston to the bottom of the nearest groove, whereby the steam is admitted behind the packing ring and presses it out against the cylinder so long as the steam is acting upon that face of the piston. The alternate action of the two rings is continued as long as the steam is acting on the piston, one of them being always pressed steam-tight against the cylinder.

In Figs. 4, 5, and 6, Plate 81, is shown one of the pistons with brass rings which are $\frac{3}{4}$ inch width and $\frac{7}{16}$ inch thickness, the piston being $3\frac{1}{4}$ inches wide.

Another form of the piston has been used in cases where the piston is desired to be flush on both faces or to fit a cylinder with flat covers: in this a circular flat head forged upon the piston rod is fitted between the turned faces of the two halves of a cast iron piston, which are held together by turned pins rivetted over, forming a hollow piston flush

on both faces, fast upon the piston rod, and without any loose part besides the two packing rings.

The ends of the rings where divided are made with a butt joint, as in Fig. 3, Plate 80; or with a lapped joint, as shown in Figs. 7 and 8, Plate 81. The piston body is turned to pass through the cylinder easily; and the joints of the rings have been found to be practically steam-tight. In some cases the joints have been tongued, as shown in Fig. 6, but in the writer's experience this has not been found requisite; the butt joint has invariably worked well, whilst it has the advantage of perfect simplicity of construction. In pistons where the packing ring travels over the opening of the cylinder port a small stop is fixed in the bottom of the groove, entering a short slot in the packing ring, to prevent the ends of the ring coming opposite the cylinder port, but still leaving the ring free to travel round a little in the piston grooves: but it is preferred for the packing rings not to travel over the cylinder ports.

Another form of joint for the packing rings is shown in Figs. 9, 10, and 11, Plate 82, intended to be used in a stationary engine with cylinder 16 inches diameter. A brass stop piece C, 1 inch thick and 4 inches long, is placed in a recess at the back of the joint, serving as a cover to the joint at the top and bottom by projecting $\frac{1}{8}$ inch in thickness on each side of the ring.

These steam-packed pistons have been used more than seven years in the locomotives of the Great Southern and Western Railway, and have proved so satisfactory and advantageous that their use has been extended to all the 94 locomotives working upon that line. The following are the results of the working in the engines running from Dublin, as regards the durability of one set of rings, the period of their wear, and the mileage of the engines whilst wearing them out. Nineteen engines working with one set of steel rings averaged 33,020 miles and 16 $\frac{1}{2}$ months' running, one engine having worked for 3 years and run as much as 98,073 miles with one set of packing rings. Five engines working with one set of brass rings under the same circumstances averaged 30,986 miles and 19 months' running, the greatest work amongst them being 2 $\frac{1}{2}$ years and 43,197 miles.

Twenty other engines with steel rings which are still in use have also averaged 40,444 miles and 21 months' work, one of these having worked for $3\frac{1}{2}$ years and run 94,399 miles with the original set of rings.

The general result of the above is that one set of steel packing rings have lasted 37,000 miles and 19 months' work, and one set of brass rings 31,000 miles and 19 months' work, the difference in durability being about 16 per cent. in favour of the steel rings. In some of the individual cases of the pistons with steel rings, a very considerable variation from the average result of 37,000 miles is found in the durability of the packing rings, some of them having lasted $2\frac{1}{2}$ times the average and some only as much below the average. In the case of the brass rings the variation is not so great, amounting to $1\frac{1}{2}$ times the average in the highest and about as much below the average in the lowest. This variation in wear has not been fully accounted for: it may have occurred from a different character of metal in the cylinders, from priming of the boiler, and from the presence of grit in the water; but the writer has reason to believe that the rings have been frequently put in to work and set with a pressure upon the cylinder from their own elasticity, thus causing a source of wear. It is found the best plan to turn the rings to the exact diameter of the cylinder, and to put them in without any spring upon them, so that they are not subjected to any wear except when the steam is acting on them. The steel rings are now slightly tempered, to admit of their being sprung into the grooves without altering their form. In all these pistons the steel packing rings were $\frac{3}{8}$ inch thick originally and $\frac{3}{8}$ inch wide, and they were worn down to about $\frac{1}{8}$ inch thick in the thinnest part before being removed. The brass rings are worn down from $\frac{1}{16}$ inch until they are $\frac{1}{8}$ inch thick. Specimens are exhibited of steel rings from four engines that have worked 38000, 61000, 84000, and 96000 miles respectively since first put into the pistons. It must be remarked that when opportunities occur, as when engines are under repair, the rings are taken out and re-set to the size of the cylinder.

It is found in practice that two steam ports of $\frac{1}{8}$ inch diameter are quite sufficient for each of the steel packing rings, drilled in the

position B B shown in the drawings, Plates 80 to 83. The rings must be made to fit easily in their grooves, so as to move freely, with a clearance of $\frac{1}{16}$ inch at the bottom of the grooves for the steam to pass round behind the rings. No difficulty has been experienced from the steam passages becoming stopped up with a moderate use of tallow in the cylinders.

The use of this piston packing in locomotive engines has been productive of economy by reducing the friction and by prolonging the wear of both pistons and cylinders. It will be observed that only one ring is in action at the same time, and that when the steam is shut off, as in descending inclines and approaching stations, the piston is free to move without any friction. The cylinders of the four engines from which the specimen rings exhibited have been taken show a highly polished surface, are very little worn, and are nearly parallel throughout. The operation of putting in these rings so as simply to fit the cylinder is extremely easy, whilst great care and skill are required in giving springs the requisite degree of elasticity and in making them maintain it.

A set of brass packing rings is also exhibited, taken out of the pistons of a pair of vertical Stationary Engine cylinders at the Dublin railway station, in which they have been in constant work for the last four years, with a pressure of 50 lbs. steam. The diameter of the cylinders is $19\frac{1}{4}$ inches, and the rings were originally $\frac{5}{8}$ inch thick and $\frac{3}{4}$ inch wide; they are now worn down to $\frac{5}{16}$ inch thick.

A number of stationary engine pistons are working with these packing rings, and they have proved very durable and thoroughly satisfactory, giving an advantage in reduction of friction, and in preserving the cylinder face in perfect condition. In one case of the engine of the Oldbawn Paper Mill near Dublin, with vertical cylinder 18 inches diameter and $2\frac{1}{2}$ feet stroke, working with 50 lbs. steam, the cylinder had previously been worn considerably out of truth and much grooved, and one of these pistons was put in having two steel rings of $\frac{3}{4}$ inch width and $\frac{3}{8}$ inch thickness, and was in constant work for four years without the packing rings requiring renewal. They have lately been taken out for examination, and were found to be still

$\frac{1}{4}$ inch thick ; and the cylinder from its previous defective condition has been brought completely to truth throughout, with a highly polished surface.

These packing rings have also been used for four years for Pump Buckets, and have proved very satisfactory. In one case of a double-acting pump 8 inches diameter, shown in Fig. 12, Plate 83, the two packing rings A A are of brass, $\frac{3}{8}$ inch wide and $\frac{5}{16}$ inch thick, and are pressed out by the pressure of the water acting at the alternate faces of the bucket through two ports B B, $\frac{1}{8}$ inch diameter, similar to those in the steam pistons. This pump had two years' constant work at quarries and bridge foundations upon the Great Southern and Western Railway, before the packing rings required renewal.

In the case of single-acting pumps the bucket has only a single packing ring with ports opening from the upper side, as shown in Fig. 13, Plate 83, which represents a pump bucket 5 inches diameter that has been working constantly for $2\frac{1}{2}$ years at a station on the railway near Dublin. This bucket is now exhibited, having been taken out for this purpose : the packing ring A was originally $\frac{1}{2}$ inch wide and $\frac{1}{4}$ inch thick, and has worn less than $\frac{1}{16}$ inch in the $2\frac{1}{2}$ years that it has been working up to the present time. As the diameter in this case is too small to allow of the ring being sprung over the body of the bucket into its place, it is put in by means of a junk ring D screwed on at the under side of the bucket, as shown in the drawing.

An application of the same construction of packing that has also been made to the gland packing of a 9 inch pump plunger is shown in Fig. 14, Plate 83 ; in which two brass packing rings are used, $\frac{1}{4}$ inch wide and $\frac{3}{8}$ inch thick, just like the piston packing rings, except that they act in the opposite direction, being pressed inwards upon the plunger by the pressure of the water through the ports B B.

Mr. MILLER exhibited specimens of the steel packing rings from the pistons of four locomotives which had run from 38000 to 96000 miles; and also the brass packing rings from the pistons of the stationary engine, together with the bucket of the 5 inch single-acting pump referred to in the paper.

Mr. J. FERNIE was glad that the subject of packing rings for pistons, which were such an important part of a steam engine, had been brought forward in the paper just read. He observed that steel packing rings had not been found to wear well in other instances in which they had been tried, and moreover they cut the cylinders; and he enquired whether the cylinders in which the steel rings had been working for so long a time were made of a very hard quality of metal.

Mr. MILLER replied that the cylinders were cast as hard as they could be made, consistently with allowing of the subsequent boring. The packing rings were made of common shear steel, and sometimes wore down irregularly in thickness, but in many cases the wear was regular.

Mr. J. FERNIE asked how the steel rings were made.

Mr. MILLER said the steel was rolled in lengths of the required shape, but slightly tapering in section from the outer to the inner face, so that when bent into a circle the two edges of the ring became nearly parallel, giving the same depth of ring throughout its whole thickness. The bar was then bent in a miniature plate-bending machine, hammered to the size of the cylinder, and fitted into the groove in the piston by simply filing, without any other work being spent upon it. At first the rings were turned in a lathe out of a steel cylinder and then cut across, but it was found better to get steel rolled of the proper section for the purpose, and afterwards bend it and fit it by filing.

Mr. F. J. BRAMWELL enquired what amount of spring was given to the packing rings before they were put in their place, and whether the piston had ever been tried without admitting the steam behind the rings, in order to see how far it would be rendered steam-tight by the pressure of the rings alone without the steam behind them.

Mr. MILLER explained that the packing rings were put in without any amount of spring of their own, being made no larger than the

diameter of the cylinder, in order that there might be no pressure against the cylinder and therefore no wear whilst running with the steam shut off.

Mr. J. FERNIE remarked that the steel packing rings in Mr. Ramsbottom's piston, generally three in number, were set with a certain amount of spring in themselves, by which the required pressure against the cylinder was obtained; and that plan required the cylinders to be of rather hard metal to stand the constant pressure in working. He enquired whether the brass packing rings that had been used had been adopted for the purpose of working in soft cylinders.

Mr. MILLER said the rings first used with this mode of packing were brass, and after some time a set of steel rings was tried, the experiment being proceeded with rather cautiously from fear that the steel rings might cut the cylinder; but it was found they did not do so, if fitted in without any spring whatever in the rings themselves, but with only the steam behind pressing them against the cylinder. The result was that it very rarely occurred now that a cylinder required rebor-ing: the cylinders not only preserved a fine smooth surface, but kept more parallel than under the old modes of packing the pistons. The reason of using the steel rings and discarding the brass was that the steel lasted about twice as long.

Mr. J. FERNIE asked what was the weight of the steam-packed piston for a locomotive cylinder of 15 inches diameter.

Mr. MILLER replied that the weight of a piston of that diameter was $64\frac{1}{2}$ lbs. without the rod, which was $2\frac{3}{8}$ inches diameter: the piston was 2 inches thick.

Mr. J. FERNIE said they had tried some pistons on the Midland Railway on this principle of packing by the pressure of the steam behind the rings; they were wrought iron pistons forged solid on the piston rods, and the packing rings were of brass $\frac{1}{2}$ inch square in section. A very long mileage was got out of these rings, but it was found that with solid pistons there was a great deal of trouble from the necessity of getting the crossheads off to draw the piston out, whenever it was wanted to do anything to the piston or look at the packing rings; and they had therefore now gone back to the old fashioned piston with a

junk ring bolted on the face for getting at the packing rings. The bearing surface was now reduced to 1 inch in the pistons; there were two $\frac{1}{2}$ inch packing rings, and these gave a longer mileage than used to be got out of two $1\frac{1}{2}$ inch rings. A great width of bearing surface was not required, but a small bearing surface was preferable, provided the rings were made to fit the cylinder accurately all round; and Mr. Ramsbottom certainly had the credit of having first called attention to the advantage of narrow packing rings well fitted. The 16 inch piston now used in the Midland locomotives weighed $1\frac{3}{4}$ cwt. including the piston rod, having been reduced in weight 28 lbs. below the previous make, in consequence of which a longer mileage was got out of the packing rings; the wear of the cylinders was also greatly reduced, a highly polished surface being maintained. Formerly there used to be a great deal of trouble from the cylinders wanting reborings, but now with the narrow packing rings and light pistons this was quite removed. He thought highly of the steam-packed piston, and the results obtained in the durability of the packing rings were certainly very extraordinary, 90,000 miles far exceeding any mileage previously attained. In his own experience about 20,000 miles was the durability of a set of $\frac{1}{2}$ inch square brass rings, and then they would want setting up twice or three times during that period. He enquired how often the steel packing rings had been set up before they were worn out.

Mr. MILLER said the packing rings had not been examined and set up at stated times, but whenever the engine happened to be in for casual repairs the piston was taken out, and the rings examined and set out if required, by slightly hammering them all round to bring them again up to the exact diameter of the cylinder: or they were replaced by new rings if worn out. The results of mileage with the different sets of rings were drawn from a return of the exact mileage of all the engines that were working under his own observation.

Mr. J. FERNIE enquired whether the application of the packing rings which had been described for the gland packing of a pump plunger had been tried also for the stuffing-boxes of piston rods in steam engines, in which the want of a good packing was a source of great wear and tear.

Mr. MILLER replied that he had not yet tried the packing for that purpose.

Mr. F. J. BRAMWELL enquired whether the brass rings in the Midland piston that had been referred to were set to a larger diameter than the cylinder, and how the pressure against the cylinder was obtained, as he supposed the brass rings would not keep their elasticity long by themselves; and he asked what amount of pressure they exerted against the cylinder.

Mr. J. FERNIE replied that the brass packing rings were $\frac{1}{4}$ inch square in section, and the two rings were turned $\frac{1}{8}$ inch larger than the cylinder; a wrought iron ring $\frac{3}{16}$ inch thick was placed inside the packing rings, and then inside that a single light hoop spring of steel $\frac{1}{8}$ inch thick at the ends and $\frac{3}{8}$ inch thick in the centre, so as to maintain a uniform pressure all round the brass packing rings. The inside spring had its ends hooked, and was easily got out with a pair of tongs; and the pressure it produced on the packing rings being very light, the friction against the cylinder was so small that the piston could be pushed along in the cylinder by hand; but when the packing rings were set up by separate springs, as in the old construction of piston, it required a pinch bar to be used for the purpose of moving the piston in the cylinder.

Mr. F. J. BRAMWELL enquired whether the pressure of the packing rings against the cylinder was as great per square inch when springs were used as with the full pressure of the steam behind the rings in the steam-packed piston.

Mr. J. FERNIE could not say what amount of pressure per square inch was obtained with the springs, but in the steam-packed piston he expected the pressure behind the rings would be attenuated by the steam having to pass through only two holes of very small size, so that the full pressure would not be exerted upon the rings.

Mr. F. J. BRAMWELL remarked that if that were the case the pressure would be greater in a long stroke than in a short one, if there were no leakage of steam past the edge of the rings, as the steam would have more time to get behind them; or else the holes must be made smaller for a longer stroke. But he thought probably there would always be nearly the full pressure of the steam behind the

rings that there was in the cylinder, judging from the quickness with which the steam filled the cylinder of an indicator through a small orifice.

Mr. MILLER said that with the brass packing rings first tried the holes behind the rings were drilled $\frac{1}{4}$ inch diameter, but that size was found too large, and they were therefore reduced to $\frac{1}{8}$ inch diameter, which proved to be sufficient for obtaining the required pressure to make the piston steam-tight in the cylinder. The pressure was greatest at the commencement of the stroke and decreased after the steam was cut off in the cylinder; and the consequence of this diminution of pressure together with the greater speed of the piston at the middle of the stroke was that the surface of the cylinder wore more parallel and to a smaller extent than when springs were used, because the latter exerted an equal pressure throughout the entire stroke and were always in action whether the steam was in the cylinder or not.

The CHAIRMAN enquired whether the piston body was turned much smaller than the cylinder or only an easy fit.

Mr. MILLER replied that the piston body was turned down to about $\frac{1}{32}$ inch smaller diameter than the cylinder, so as to pass easily through it.

Mr. D. JOY observed that in a locomotive piston with cast iron packing rings of light section he had found the pressure against the cylinder to be rather less than $3\frac{1}{2}$ lbs. per square inch. He thought cast iron was better for the packing rings than either brass or steel, being harder than brass and not so likely to cut the cylinder as steel might be. Turned cast iron packing rings $\frac{1}{4}$ inch or $\frac{3}{8}$ inch thick could readily be sprung over a piston 16 inches in diameter, and would be strong enough to maintain their elasticity.

Mr. MILLER said he had not tried cast iron for the packing rings, as they were so small that he thought it would hardly be safe, and if made as much as $\frac{1}{2}$ inch thick they would be too stiff to be sufficiently acted upon by the steam behind. In a stationary engine piston of larger diameter cast iron packing rings might do well enough.

Mr. J. FERNIE asked whether the steam-packed pistons worked equally well in running down hill as on level lines of railway.

Mr. MILLER replied that there were many inclines on the line, the maximum gradient being 1 in 100, and the pistons were found to work perfectly well down hill. They had the advantage of being free from pressure of the packing when the engine was running with the steam shut off, at which time consequently there was no lubrication for the piston.

The CHAIRMAN enquired whether there had been an opportunity of comparing the working of the new pistons with any of the older forms of pistons that were still used on many railways, and whether they required as much looking after as the old pistons. The ordinary make of pistons with a junk ring or loose plate bolted on gave convenience for examining the packing rings without drawing the piston out of the cylinder as had to be done with the new pistons, and it would be an inconvenience therefore in the latter if the packing rings had to be looked at frequently.

Mr. MILLER said they had now discarded all the old pistons, finding them so expensive to maintain, and the new pistons required much less looking after. There was no necessity for examining them at particular times, as they remained steam-tight without any attention for many months' working; but whenever the engine was undergoing repair, advantage was taken of the opportunity to draw the pistons out and set out the rings again if they were worn. Previously with only 50 engines running four men were constantly at work repairing the pistons, but now with 94 engines running one fitter kept all the pistons in order.

Mr. F. J. BRAMWELL asked whether the packing rings filled out to the size of the cylinder as they became worn, or whether when the steam was off they returned to their original inside diameter.

Mr. MILLER replied that when taken out after a great deal of wear the packing rings were slightly smaller in diameter than the cylinder, and then required setting out by hammering. Sometimes they wore perfectly equally all round, and sometimes more at the ends or in the middle.

Mr. J. WRIGHT remarked that in two double-acting forcing pumps of $8\frac{1}{2}$ inches diameter which he had erected at the Bishop Auckland Water Works, for pumping the water under a head of

270 feet, he had adopted the same plan of packing for the solid piston, using two steel packing rings with the water pressure acting behind them: these worked well during the $2\frac{1}{2}$ years that the engines were under his observation, requiring no repairs during that time. Similar packing rings were used for the steam cylinders. One great advantage in this plan of packing was that only one packing ring was in action at a time, while the other ring which had no pressure upon it did not rub against the pump barrel or cylinder in the return stroke, avoiding unnecessary friction; but in ordinary pistons both rings were pressing against the cylinder constantly, which was not necessary, since the new plan of packing made the pistons tight enough for all practical purposes. He enquired whether there had been any experience of the steam-packed piston in a steam hammer, as he was about to adopt that mode of packing for a steam hammer which he was making for his own works with cylinder $22\frac{1}{2}$ inches diameter and 6 feet stroke; and he thought it would be an advantage to have the piston free from the friction of the steam-tight rings when the hammer was falling, by the steam pressure being then removed from behind them.

The CHAIRMAN said he had made the piston packing described in the paper for many locomotive engines, but was using Mr. Ramsbottom's packing rings for all his steam hammers, the largest of which was 26 inches in diameter.

Mr. F. J. BRAMWELL said he had had some experience of Mr. Ramsbottom's packing rings in steam hammers with cylinders of 18 inches diameter, and also in a 27 inch steam hammer which gave great satisfaction; and he was consequently putting up a hammer with a 36 inch cylinder with the same mode of packing.

The CHAIRMAN asked what was the largest size of steam engine piston now at work with the new packing.

Mr. MILLER replied that the largest steam-packed piston was one of 24 inches diameter made for a saw mill in Dublin. In the case of the Oldbawn engine, mentioned in the paper, the cylinder was now as good as a cylinder could be; parallel, very smooth, and true in diameter: five years ago this same cylinder was worn so badly by the former piston that it was about to be replaced by a new one; but it

was set to work again for trial with the new piston without reboring the cylinder, and had since got into the present perfect condition, the steel rings having the effect of gradually wearing away all the irregularities of the surface until it was brought to a perfect cylindrical form, when the rings would bear with a perfectly equal pressure round their whole circumference, and no further wear was perceptible.

The CHAIRMAN asked whether the half lapped joint of the packing rings shown in one of the drawings (Fig. 8, Plate 81) was used, and how it was made.

Mr. MILLER said he had some packing rings, both of steel and of iron, working with the lapped joints. The notch at each end of the ring was cut out by a slotting machine, before the bar forming the ring was bent to the shape of the cylinder. The plain brass rings with butt joints were turned out of a gun-metal cylinder, and then cut: he had also tried rings made of yellow rolled brass, rolled into bars and then bent to the shape of the cylinder, but these did not wear so well as gun-metal.

Mr. J. FERNIE said he had also tried to make packing rings out of rolled brass, by cutting it into rods of the required length and bending them to shape; but they were too soft for work, and he had to return to the cast gun-metal rings.

The CHAIRMAN remarked that after making and employing a great many different descriptions of pistons he thought the steam-packed piston described in the paper was a very good one, and it had the great advantage of being very simple in construction. Formerly it was a great object to keep the steam out of the piston, on account of the internal packing springs; but in this piston the steam was admitted inside to act as the spring upon the packing. The practical feature of the new pistons was their great simplicity of construction: but to Mr. Ramsbottom was certainly due the credit of first simplifying the construction of pistons to so great an extent. He considered the piston now described ought undoubtedly to work well, because there was so little about it to get out of order, and it could not do otherwise than prove highly satisfactory. He proposed a vote of thanks to Mr. Miller for his paper, which was passed.

The following paper was then read:—

ON MACHINERY FOR THE MANUFACTURE OF GUNSTOCKS.

BY MR. THOMAS GREENWOOD, OF LEEDS.

Of all the various articles into which wood is shaped by machinery few have presented greater difficulties than Gunstocks. The irregularity of their form and the intricate shaping required to receive the metallic parts of the gun have rendered so many separate operations necessary, requiring such a variety of machines, that it can scarcely be matter of surprise that gunstocks have hitherto been made by hand in all the leading gunmaking localities both in this country and on the continent: and this might have continued to be the case, had not other reasons arisen besides the economy of labour to be effected by the introduction of machinery. In military arms, where very large numbers of one pattern are required, the desirability of making all the parts interchangeable naturally suggested itself; but it required years of thought before this principle could be fully developed and practically carried out. In order to carry it out practically, it is required not only that the gunstock should be made perfect, but that each of the metallic parts should be equally perfect. Hence the manufacture of each separate part by machinery had to be studied and accomplished, involving no small amount of ingenuity to make perfectly by machinery what had hitherto been done easily and cheaply by hand, though wanting in the exactness necessary to form the parts of an interchangeable gun. Possibly if the demand had not been for a national purpose the manufacture of machine-made guns might yet have been unattained: whatever the cause however, gunmaking by machinery on the interchangeable principle is now successfully accomplished.

The object of the present paper is to explain the process of making gunstocks by machinery, and to describe some of the processes in detail. To secure success there is one condition which must be rigidly

observed throughout this manufacture, namely perfect accuracy in each operation. In a manufacture where twenty operations are built upon one another, each depending for its accuracy upon a previous one, it is evident how important this condition is to success. The following is the entire series of successive operations, 23 in number, which are performed by a set of machines for shaping and finishing the stocks for rifles, each operation advancing the stock a step further from the original rough bar of wood towards its completion in the required form.

1. The upper edge of the stock is cut nearly in a line with the centre of the barrel, and is finished with an oblique cross cut at the breech; the muzzle end is also cross cut nearly to the correct length. This operation is called "slabbing".
2. The centres are made in the butt and muzzle ready for the rough-turning machine.
3. The fore end of the stock is rough-turned.
4. The butt end of the stock is rough-turned.
5. Five flat places are cut on the right hand side of the stock, and two on the left side. This operation is called "spotting".
6. The hollow bed to receive the barrel is cut out, and the tang of the breech screw is let in. This operation is called "bedding the barrel".
7. This is a hand operation, consisting in squaring the conical recess made by the cutter in the previous operation, to receive the taper projection under the tang of the breech piece; and the corner is rounded off to fit the hollow under the tang.
8. The stock is sawn to the exact length at both ends, and the butt end shaped to the form of the butt plate, by means of a revolving outter.
9. The flat sides are planed where the lock plate is inserted, and the side caps are let in, which act as nuts for the screws holding on the lock: also the upper edges of the recess for the barrel are profiled, and the upper and under edges of the butt end of the stock.
10. The tang of the butt plate is let in, the three holes for the screws are bored, and the two end holes also tapped.
11. The corner under the tang of the butt plate is rounded off by hand.
12. The lock is bedded. The lock bedding machine is described subsequently in detail and shown in Plates 84 to 88.
13. The end of the curved recess for the cone seat where it joints against the lock plate is squared by hand.
14. The trigger guard is bedded and the screw holes drilled, and the recess for the trigger plate is cut and the stop for the ramrod let in.

15. The stock is cut under the bands from a copy, and the nose cap is let on.
16. The stock is cut between the bands. The machine for this purpose is also described subsequently in detail and shown in Plates 89 to 92.
17. The arris at the extreme muzzle end of the stock under the flange of the nose cap is taken off by hand.
18. The butt end of the stock is finish-turned in a copying lathe.
19. The fore end of the stock between the lock and the first band is finish-turned in a copying lathe.
20. The groove is cut for the ramrod.
21. The recess to receive the ramrod spring is cut out, and the transverse pin hole for fixing the spring is bored.
22. The hole for the ramrod is bored in continuation of the groove.
23. The holes for fixing the lock plate are bored, and also the screw hole for the tang of the breech screw, the screw hole for the nose cap, and the pin hole to fix one end of the trigger guard.

The Lock Bedding Machine, for performing the 12th operation of cutting out the bed or recess to receive the lock, is shown in Plates 84 to 88. Fig. 1, Plate 84, is a front elevation of the machine; Fig. 2, Plate 85, a side elevation partly in section; and Fig. 3, Plate 86, a plan with the upper portion of the framing removed.

In this machine five separate operations are successively performed to cut and shape the recess for the lock, with one fixing of the gunstock in the machine. The five cutters or drills A, Figs. 1 and 2, Plates 84 and 85, are fixed each in a vertical spindle B carried on the vertical slide C, as shown enlarged in Figs. 4 and 5, Plates 87 and 88; the drill slides C are mounted on the circumference of the circular cage D, which turns round on the vertical centre shaft E, Fig. 5. Each drill slide C has a circular or transverse motion to a short extent round the circumference of the cage D, and also a vertical motion, and is moved both transversely and vertically by the lever F provided with universal joints. A plain cylindrical driving wheel G at the top of the machine, turned perfectly true, drives each of the five drills by friction, by means of the small driving roller H on the top of the drill spindle, Fig. 3, Plate 86. The main driving wheel G runs loose on the centre shaft E, being driven by the belt pulley I above, Figs. 1 and 2. The vertical drill slides C are each held up by a coiled spring J, Fig. 5, which lifts the roller H of the drill spindle out of gear with the driving

wheel G when not in use, so that the drill does not revolve until pressed down by the handle F.

The gunstock K, Fig. 4, Plate 87, is fixed longitudinally upon a horizontal sliding table L, and is held in its proper position by a portion of a barrel and tang M sufficient to keep it firm when pressed home by the eccentric N. The horizontal table L can be moved freely backwards and forwards longitudinally by the hand lever O, Fig. 2, by means of a toothed segment gearing into a rack on the underside of the table. The centre shaft E of the circular cage D carrying the drills is supported in a frame bridging over the table L. Alongside the gunstock upon the same sliding table L is fixed the pattern P, or "former" as it is termed, made of hardened cast steel, which is an exact copy both in size and form of the recess to be cut in the stock. The shape of the pattern P is followed by a tracer R, Fig. 4, fixed parallel to the drill A in the drill slide C. Hence if the horizontal table L be moved longitudinally and the drill slide C transversely and vertically, by the combination of these three movements every part of the pattern can be traced by the tracer R, while an exact facsimile of the pattern is being cut in the wooden gunstock by the drill A. The five drills of the machine are all of different sizes, for cutting the different portions of the recess, and each drill is accompanied with a corresponding tracer of the same size. When one drill has finished its own particular portion of the work, the circular cage D is turned round by hand to bring the next drill into operation upon the gunstock: the cage is locked by a spring as each succeeding drill is brought round into position, and is then released by the foot by the treadle S. A small fan T with two air tubes blows away the cuttings from the drill and also from the pattern.

For cutting the lock recess it is absolutely necessary that the cutter and the tracer be of exactly the same size, otherwise the recess will not correspond precisely with the pattern. In order to maintain perfect accuracy of the recess cut, the sockets in three of the drill spindles are bored 1-64th inch eccentric, and the shank of the cutter is turned to the same amount of eccentricity with the cutting part. The end of the spindle nose is graduated through half its circumference into fine divisions and a zero line is made upon the cutter; and when

the cutter is new or full size, and placed so that the two eccentricities counteract each other, the cutting part is perfectly true. But as soon as the cutter has been made sensibly less by sharpening, it is turned round one or two divisions in the drill spindle, so as to impart just as much eccentricity to the cutting tool as the sharpening has reduced it in diameter, thus causing the cutter to continue to describe a circle exactly the size of the tracer.

The following are the operations performed by each of the five drills in succession in order to cut out the whole of the recess for bedding the lock. The first drill cuts out the recess to receive the lock plate; and the tracer for this operation is provided with a cross piece, which reaches across the entire width of the recess in the pattern, so as to prevent the tracer from being pushed down into the pattern lower than the depth of the lock plate. The second drill bores out the hole for the shank of the "sear", and also a hole for the sear spring screw. The third drill bores two holes for the bridle screw heads. The fourth drill cuts out the principal recesses below the lock plate, and partially cuts out the curved recess for the cone seat. The fifth drill cuts out the rear end of the recess to make room for the heel of the sear spring, and also cuts out a small notch on the lower side of the recess to receive the end of the swivel when the hammer is down. The first, fourth, and fifth drills are the three which have their shanks turned eccentric to allow of adjustment for wear; while the second and third drills, having merely to bore out plain circular screw holes, are fixed concentric in their spindles.

The operation of cutting the recess for the gun lock is performed with great rapidity by this machine, which will recess upwards of 1000 gunstocks per week. This lock bedding machine may be taken as a type of the machines arranged for copying from the interior of a pattern: several of the machines used in the manufacture of gunstocks are of similar construction.

The Shaping Machine for shaping the gunstock between the bands, which is the other machine selected for description in detail, is one copying from an exterior pattern, and performs the 16th operation of shaping the external portion of the stock between the bands.

Figs. 6 and 7, Plate 89, are a side elevation and end elevation of the shaping machine, and Figs. 8, 9, and 10, Plates 90 to 92, show its construction more in detail to a larger scale.

In this machine the pattern to be copied consists of a series of cams A A, Figs. 8 and 9, Plates 90 and 91, mounted upon a horizontal shaft immediately over and parallel to the gunstock B; and the shape of the pattern is transferred to the gunstock by the revolving cutters C mounted in the rocking levers D, at the extremities of which are the tracers that follow the circumference of the pattern cams. The gunstock B is fixed upon a bar or mandril E, which corresponds exactly with the gun barrel and fits precisely into the groove cut in the stock in one of the earlier operations to receive the barrel; and this barrel groove serves as the fixed accurate basis for the present and all the subsequent operations, as well as in the previous operation of bedding the lock, thus ensuring absolute identity in all the stocks. The mandril E is supported by three hollow journals F, which revolve in three bearings on the frame of the machine; and the gunstock B is slid inside these journals upon the mandril, and is held in its place by a spring at the muzzle end, shown dotted in Fig. 8, and by two set screws in the other two hollow journals.

There are four revolving cutters C C, Fig. 10, Plate 92, mounted in the four rocking levers D. The bearings of the cutter shaft are carried in a forked swivelling frame G, Fig. 8, inserted in a socket in the top of the rocking lever D, so that the cutter shaft can be set exactly parallel to the axis of the gunstock or slightly inclined to it, according to the shape of the stock; on each prong of the frame G is an adjustable tracer I, Fig. 9, for tracing the form of the pattern cam A. The cam shaft and the mandril E are geared together by a pair of equal spur wheels at each end, and the gunstock is turned round through half a revolution by the hand-wheel H as the shaping proceeds, the cutters being driven by belts J J from the bottom pulleys, Figs. 6 and 7, Plate 89. The cutting blades are screwed to a cast iron block, which is shaped with an undulating surface, as shown in Figs. 8 and 10, so as to present the cutting edges at an angle to the axis of the gunstock and thus ensure a smooth cut across the grain of the wood with somewhat of a paring action.

The portion of the gunstock next to the bands is first shaped by the cutters on one side of the machine, which are brought up by means of the treadle K, Figs. 6 and 7, Plate 89, and the flat steel spring L, Fig. 9. The thin end of the spring L bears against the lower end of the rocking lever D, and presses the tracers I against the pattern cams A. The spring L ensures the tracers keeping in close contact with the cams throughout their revolution, whilst the treadle is kept pressed down by the foot; it also ensures a softer action of the cutters as they are brought up against the wood. A counter spring M on the opposite side of the rocking lever D serves to keep it steady, and to throw off the cutters out of action when the treadle is released. The second pair of cutters on the other side of the machine is then brought up into action in the same manner by the other treadle; and the gunstock being turned round through the remaining half revolution is thus reduced to the finished shape in one revolution of the hand-wheel H.

The other machines of the series are similar in the principles of construction, differing merely in the details of arrangement for performing the special operation intended. By the employment of machinery in this manner, strict accuracy of work is obtained, and all the separate portions of the gun are interchangeable with any gunstock. Although this machinery requires much greater delicacy and accuracy of workmanship and much more careful fitting than ordinary wood working machinery, and is consequently much more expensive, yet the saving in cost of production of gunstocks fully justifies the large outlay incurred in the first cost of the machinery, which is amply repaid by the intricate nature of the operations performed, and the rapidity and exactness with which the work is produced by these machines, as has already been shown to be the case by the success that has attended the government factory at Enfield, where similar machinery is employed for the manufacture of gunstocks.

Mr. GREENWOOD exhibited the lock bedding machine in complete working order, together with the shaping machine for shaping the gunstock between the bands ; and also an entire set of the gunstocks from each stage of the manufacture, showing the condition of the stock after each of the 23 operations, advancing step by step from the original rough wood blank to its final completion in the required form. He explained that of the 23 operations 19 were performed by machinery and 4 by hand, namely Nos. 7, 11, 13, and 17 in the series described in the paper ; and these latter it was expected would be reduced shortly to only one hand operation of very small amount.

The CHAIRMAN thought the subject of the paper was a very interesting and important one for the gunmakers of Birmingham ; and he enquired whether any of the machines described were at work there for the manufacture of gunstocks.

Mr. GREENWOOD replied that there were not any of the machines at work yet in Birmingham, but a complete set of them was in operation at Enfield, where they had been in use for several years ; and also a nearly similar set at the London Armoury Company's works in London. The machines now exhibited were constructed for making only one length of gunstock, and some modifications had therefore been introduced for simplifying the construction and mode of driving ; but the machines in use at Enfield would take in three different lengths of gunstocks, namely carbines, short Enfields, and ordinary long Enfields, the last of which formed the greater proportion of the guns manufactured. At Enfield with two sets of the machines 2000 gunstocks per week on the average were produced ; but at that rate of work the machines were not fully employed, and in full work one set of machinery would produce 1200 gunstocks per week. At present the gunmakers of Birmingham had to pay a high price to have their gunstocks made by machinery in London, in order to secure greater accuracy and finish of workmanship than was obtained in hand work.

The CHAIRMAN remarked that the machine work certainly appeared much superior in quality to that done by hand. He enquired whether the lock bedding process performed by the machine now exhibited was reckoned as five separate processes in the series of operations for making a gunstock.

Mr. GREENWOOD replied that there were 19 separate machines in the complete set, and the lock bedding was counted as only one operation, though divided into five parts for convenience and accuracy of work, as had been described, since it was necessary to be very particular in ensuring perfect accuracy in every part of the work.

The CHAIRMAN enquired where the original machines for the manufacture of gunstocks had been used, from which the machinery now described had been derived.

Mr. GREENWOOD said the gunstock machinery was of American origin, and the American government had been occupied for the last twenty years in perfecting the manufacture of guns by machinery at the armouries of Springfield and Harper's Ferry. At the time of the Crimean war Mr. John Anderson, Col. Burn, and Lieut. Warlow were sent over from England as a commission to investigate the manufacture of arms in the United States, and an arrangement was made with the Ames Company to supply two or three sets of machines to this country, the American government consenting to furnish all the information in their power on the subject. The first attempts however at the use of machinery proved fruitless, as several of the machines first made failed and had to be abandoned; but the work was resumed, and resulted in the machinery now in use in the Enfield factory. The original machinery was intended to turn out 500 gunstocks per week, and had since then been supplemented by further machinery from America and also from his own works, so as to produce now 2000 gunstocks per week. The machines supplied from his own works had been constructed for the purpose of making different lengths of Enfield gunstocks in the same machines, so as to prevent the necessity of having different sets of machines for different sizes of gunstocks. Two or three other sets of machinery were also made subsequently by the Ames Company, but none had been got successfully to work except that supplied to the London Armoury Company; and the Russian government purchased a set through Col. Colt, which had also not been brought into actual operation at present. The machinery at Enfield was at first worked under the superintendence of men sent over from America; but more guns were now being turned out there than at that time, and the machines were working very successfully, producing very smooth and accurate work.

The CHAIRMAN thought the construction of the machines must be rendered considerably more complicated if it were attempted to make different sizes of gunstocks in the same machines, instead of employing a second set of machinery for a different size of stock.

Mr. GREENWOOD observed that the shape of the work could be changed to a considerable extent in the same machine by simply changing the pattern that was being copied, and having the cutting tools so shaped that they would follow any pattern required. One essential condition of success was that the cutters should be adjusted with extreme accuracy and maintained with a very sharp cutting edge ; and they were driven at a high speed, making from 5000 to 6000 revolutions per minute in the lock bedding machine, and about 2000 revolutions per minute in the shaping machine.

The CHAIRMAN enquired what was the cost of a complete set of the gunstock machinery ; and how the gunstock was adjusted with the required accuracy to its proper position in the several machines, so that each machine should follow and take up the work correctly from the preceding one.

Mr. GREENWOOD said the cost of a set of the machines complete with all accessories would be about £8000 for producing 500 gunstocks per week. The machines were all arranged in a row, so that the work was passed on from one to another successively throughout the entire series ; and one considerable difficulty that had been met with was to get some simple and efficient means of readily fixing the gunstock in its proper position in each machine, so as to ensure exact correspondence in the shaping of all the stocks. The first four operations consisted simply in reducing the original wood blank roughly to the shape of the stock, and no accuracy of adjustment was needed in them ; but in the fifth operation, termed " spotting," the accuracy commenced, the " spots " or flat places cut on each side of the stock in this operation being portions of one plane and forming the basis of adjustment for the sixth operation, in which the groove was cut for the barrel, the stock being fixed in the proper position in the machine by means of the " spots " previously cut on it. The barrel groove then became the basis for all the subsequent operations, each machine having a mandril exactly corresponding with the

gunbarrel, upon which the stock was readily slid endways, and pushed home to the squared end of the groove, and then fixed in its place.

The CHAIRMAN enquired what amount of wear there was upon the principal bearings of the lock bedding machine, and how they were kept in repair.

Mr. GREENWOOD replied that there would be no difficulty in keeping the bearings completely in order, as all the bushes were of hardened steel, and the work was fitted with such accuracy that the circular cage and the drill slides were moved easily by a light touch. The drill spindles had a conical neck at the bottom end, running in a conical steel bush hung on centres, and the top end of the spindle ran in a parallel bush, with a loose collar that took the end thrust of the drill, so that the spindle was kept perfectly free and ran very smooth and steady, without any strain under the high speed at which it was driven; a lock nut at the upper end gave the means of taking up the wear of the conical bearing at bottom and the collar at top. The small driving friction rollers at the top of the drill spindles were made of ebonite, vulcanised india-rubber with an extra quantity of sulphur in it, which was a very hard and durable material, well adapted for the purpose.

Mr. F. J. BRAMWELL asked whether that mode of driving the drill, by means of a friction roller driven by contact with the central driving drum, did not make the drill slide less easy to move laterally: he remembered in the machines made by the Ames Company a separate strap with fast and loose pulleys to each drill spindle was used in similar cases, that the movement of the drill slide might not be hindered by the friction.

Mr. GREENWOOD said the tendency of the driving drum to carry the drill slide round with it did not produce any difficulty in working the machine, and the drill slide was moved in either direction by the handle with the greatest ease and lightness; and when the handle was let go the slide was raised by the spring behind, and the friction roller thereby lifted out of contact with the driving drum. With a separate strap to each drill there was the objection that each strap had to be thrown in and out of gear successively; and the plan now adopted had therefore the advantage of greater simplicity and facility of working.

Mr. F. J. BRAMWELL observed that the advantage in machine work was very great in the facility and rapidity of fitting the work together, on account of all the parts being strictly accurate as duplicates; and the price and time of putting a gun together complete would give the best idea of the perfect uniformity and finish with which the several portions of the work were produced by the machinery. He understood that the cost of putting together at Enfield was now reduced to only $1\frac{1}{2}d.$ each, since all the parts were exact duplicates of one another, in consequence of being made by machinery. He enquired what was the time occupied in putting each gun together complete, when made by machinery.

Mr. GREENWOOD replied that the time required for putting together a gun was now only six minutes, including the ramrod, bayonet, and oiling over the stock. The lock was finished and put together beforehand ready for the workman, and the screw holes being ready drilled in the stock all he had to do was to put it into the recess in the stock and screw it in. All the other parts of the gun furniture were taken up promiscuously from a lot of each sort, and put into the stock, and the only tool used by the workman was a hand brace with a screwdriver in it.

Mr. J. FERNIE observed that he had been much interested in seeing the machinery at Enfield, and thought the lock bedding machine now exhibited was a very beautiful specimen of machinery and a decided improvement upon the machine used there, as it had no loose straps in connexion with the several drills, in consequence of the drills being driven by friction rollers by the central driving drum, and it was altogether a better arranged machine. The mode of compensating for the wear of the drills, by fixing each drill with an eccentric shank in an eccentric socket in the drill spindle, was also an ingenious contrivance, affording the means of maintaining constantly the correct size of the cutter and ensuring perfect accuracy of work, by turning the drill round a little in the socket when its diameter had become reduced by sharpening. A shaping machine similar in principle to that exhibited for shaping the outside of the stock had been employed for some time at Derby for shaping wood spokes for carriage wheels, by means of revolving cutters copying from a pattern.

He enquired what sort of copying lathe was used for turning the butt end of the stock, and how the polishing of the stock was done to finish it ready for use.

Mr. GREENWOOD replied that the stock was merely rubbed with sand paper to remove the slight roughness of the surface left by the grooving action of the cutters ; and it was then polished by hand in the ordinary manner. The lathe for turning the butt end of the stock was one of the ordinary Blanchard copying lathes, the invention of which, though generally supposed to belong to America, really belonged to South Staffordshire, the lathe having he believed been originally invented by a gentleman named Rigg, living not far from Birmingham, for the purpose of turning shoe lasts ; the invention was afterwards taken out to America, whence it returned again to this country under its present name of the Blanchard lathe, and was now employed very extensively in large numbers of manufactures.

Mr. F. J. BRAMWELL remembered having seen a lathe with a revolving cutter mounted on an oscillating frame in the Adelaide Gallery in London about 25 years ago, which copied from a complete iron pattern of the required shape, and was capable of undercutting to a certain extent ; and the same principle had been applied in Jordan's wood carving machine. In ordinary wood-working machines however the work produced was not required to fit together : but in the gunstock machinery now described absolute truth of workmanship was necessary, so that the several parts of the gun might fit in the stock with perfect accuracy.

The CHAIRMAN moved a vote of thanks to Mr. Greenwood, which was passed, for his paper and for the machines and the complete set of specimens of the gunstocks that he had exhibited.

The following paper was then read :—

DESCRIPTION OF A HYDRAULIC SHEARS AND PUNCH.

BY MR. JAMES TANGYE, OF BIRMINGHAM.

The object of this Hydraulic Shears is to afford the means of readily cutting large sections of bar iron or railway rails, with the power of one man only, and with a machine of simple and compact construction.

This shears is shown in Figs. 1 and 2, Plate 93, and consists of a strong vertical cast iron frame A A, divided in the centre horizontally, in the upper half of which the upper shear blade B is fixed; and a short hydraulic press C is cast in the lower half of the frame, having the lower shear blade D fixed upon the top of the ram of the press, which is 10 inches diameter with 3 inches length of stroke. The upper and lower castings of the frame are secured together by two bolts E E, 3 inches diameter. The box F bolted upon the side of the cylinder contains the force pump G, and serves as the reservoir for the water of the pump. The pump is worked by the lever H, and consists of a single brass casting, shown enlarged to half full size in Fig. 5, Plate 94. This pump is screwed into its place in the side of the hydraulic press C, and contains a small conical suction valve I and delivery valve K, $\frac{1}{4}$ inch diameter, held down to their seats by spiral springs. A small wire gauze guard is fixed over the outside of the inlet and outlet openings of the pump, to prevent any dirt from getting into the press cylinder. The plunger L, $\frac{3}{4}$ inch diameter and $1\frac{1}{2}$ inch stroke, is continued backwards to work in a guide socket in the end of the reservoir F, and a tongue M on the shaft of the hand lever H works in a square slot in the plunger rod.

The shear blade D, Figs. 1 and 2, Plate 93, is lowered after the cut by means of a self-acting motion connected with the force pump lever. The length of stroke of the lever is limited in ordinary

working by a stop pin fixed on the side of the cistern, which catches the lever at the bottom of its stroke; but by shifting the lever $\frac{3}{8}$ inch outwards upon the squared end of the shaft, it is made to clear this stop pin, and is pushed down into a lower position. The tongue working the plunger then advances to the position M, Fig. 5, Plate 94, its ordinary working limits being the two dotted positions O O. The prolonged end of the plunger then reaches the delivery valve K of the pump and presses it open, allowing the water to flow back from the press cylinder into the pump; and at the same time the water is allowed to flow through the centre of the plunger by a hole drilled through the entire length of the plunger. This hole is closed at the outer end by a conical escape valve P opening outwards, which is kept shut in ordinary working by the tongue M of the hand lever; but when the lever is depressed below the stop for lowering the shears, a recess in the tongue is brought over the head of the escape valve P, allowing the valve to be forced back from its seat by the water pressure, and leaving a passage open for the water to escape through the hole in the plunger back into the cistern. The act of raising the hand lever again into its working position closes the escape valve P and keeps it shut during the working of the pump. A second force pump of larger size, with 2 inches diameter of ram, is used to bring up the shears quickly to the work to be cut.

With this shears a bar of wrought iron 3 inches square is readily cut by one man, the time required being about $2\frac{1}{2}$ minutes. Different sizes of the shears are made for cutting bars up to $3\frac{1}{2}$ inches square; the smaller sizes of bars being cut off several at a time.

This hydraulic shears is found very useful in iron warehouses for cutting large bars, where the power of only one or two men is available; and also on railways for cutting the rails, for which purpose the shears can be readily carried on an ordinary platelayer's lorry, no other foundation being required, and the whole weight being only 14 cwts. In the case of cutting rails, the shear blades are made of the same shape as the outline of the two sides of the rail, as shown in Figs. 1 and 2, Plate 93, so as to cut the whole section at once and make a clean square cut.

The Hydraulic Punch, shown in Figs. 3 and 4, Plate 94, is of similar construction to the shears already described, only inverted in arrangement, having the fixed die A at the bottom, and the punch B fixed on the end of the inverted ram C of the hydraulic press, which is 6 inches diameter with 2 inches length of stroke. The box F containing the force pump G and reservoir of water is fixed on the side of the press cylinder at the top. The punch is withdrawn quickly after the stroke by means of the spiral spring E pulling up the ram; the water being allowed to escape back from the press cylinder to the cistern through the centre of the plunger by the same means as in the shears already described.

With this punch a hole 1 inch diameter is punched in a $\frac{3}{8}$ inch iron plate, with the power of one man in about half a minute. The machine is very portable, the total weight being only $4\frac{1}{2}$ cwt.; and it has been applied with advantage to punching the holes for fish bolts in railway rails, as shown in Figs. 3 and 4, Plate 94. A successful application of this machine has also been made to the manufacture of horse shoes, by punching them out cold, with the holes and countersink complete at one operation.

The Hydraulic Lifting Jack, shown in Figs. 6, 7, and 8, Plate 95, is constructed on the same plan as the shears and punch before described, as regards the force pump G, shown enlarged to half full size in Fig. 9. The jack consists of an inverted hydraulic press A, the ram of which C forms the foot upon which the jack stands, and the pump G and reservoir of water F are fixed on the opposite end of the press cylinder, and form the head of the jack. The ram C is of wrought iron, $3\frac{1}{2}$ inches diameter and 12 inches length of stroke, with the foot forged upon it; and the press cylinder A is formed of a hammered wrought iron bar, bored out of the solid, leaving $\frac{3}{8}$ inch thickness of metal for the sides of the cylinder. A claw B is forged on one side of the cylinder at the bottom, for the purpose of using the jack to lift from the bottom when required. The head F forming the reservoir of water is of malleable cast iron, fixed upon the top end of the cylinder by being bored out a tight fit and pressed on up to a shoulder.

The jack is lowered by similar means to that previously described for the shears and punch; except that instead of the water escaping through the plunger L, Fig. 9, Plate 95, the suction valve I is forced open by the same movement that presses open the delivery valve K by means of a small inclined plane upon the prolonged end of the plunger L, which passes through an eye in the stalk of the suction valve I, and draws back the valve from its seat directly after the delivery valve K has been pressed open, allowing the water to flow back into the reservoir in the contrary direction to the ordinary working.

The ram of the jack is packed with a cupped leather D, shown black in Fig. 6, Plate 95, resting in a hollow $\frac{3}{16}$ inch deep turned in the top of the ram. These leathers have been found thoroughly successful in standing the pressure and wear, the same leathers having been in regular work for several years without requiring renewal. The force pump plunger L in the lifting jack and also in the shears and punch is packed with a narrow strip of leather $\frac{3}{16}$ inch wide, coiled round spirally in a groove turned near the bottom of the plunger, as shown in Figs. 5 and 9, with the ends of the strip bevilled off to fill up the groove close.

The hydraulic jack shown in Plate 95 is for lifting 30 tons, and several different sizes are made for weights from 4 to 60 tons. The head of the jack is prevented from turning round by a sliding block working in a longitudinal groove E in the ram; but by withdrawing the screw that fixes the block the head is allowed to turn freely with the load upon it. The hydraulic jack is convenient for use with heavy weights, from the great power obtained, one man being able to lift readily 30 tons and upwards; and from the lightness of construction, the 30 ton jack weighing only about $1\frac{1}{2}$ cwt. At the same time the loss of power from friction is comparatively small; and the small extent of wear to which the working parts are subjected gives great durability and freedom from risk of derangement.

Mr. TANGYE exhibited a specimen of the hydraulic lifting jack and of the force pump used in the hydraulic shears and punch, together with specimens of bars and rails sheared and punched by them. He explained that the shearing machine was a modification of the hydraulic shearing press described at a former meeting of the Institution in 1858, the present shears and punch being made much smaller and lighter, so as to be easily portable and to give the means of readily shearing or punching bars or rails by the power of one man.

The CHAIRMAN enquired whether any of the hydraulic shears were in use on railways for cutting rails.

Mr. TANGYE replied that two or three hydraulic shears were at work on railways for that purpose, the first having been applied about two years ago; and some were employed in iron warehouses for cutting the bars of iron, one having been in use now for five years.

Mr. G. M. MILLER thought the shears would be a useful and convenient machine for use on a railway, particularly on curves where the joints of the inner rail overtook those of the outer, so that every third or fourth rail on the inner side had to be cut shorter, in order to bring the joints opposite each other and keep the sleepers square across the line; but he thought it would be desirable to get a smoother cut than was shown in the rails exhibited. He enquired whether the rails were sheared cold, and how the cutters were found to stand the work.

Mr. TANGYE said the rails were sheared cold, and the cutters stood well when of proper quality of steel. Several thousands of cuts had been made with the machine first constructed, without the cutters requiring renewal yet; and a machine of the size shown in the drawings was strong enough for cutting bars of iron 3 inches square. The sheared rails exhibited were not favourable specimens of the cut made by the machine, the cutters not having been good in this case; but the machine generally sheared tolerably smooth, leaving the ends of the rails quite ready to go together without any labour of dressing them off for the purpose.

The CHAIRMAN asked whether the hydraulic lifting jack had been in use for any length of time.

Mr. TANGYE replied that in its present form, with the force pump and reservoir of water contained inside the head of the jack, it had been in use about eight months; but a previous make, similar in construction but having the pump outside the jack, had been in use for five years. About 200 of the jacks had already been made of various sizes.

Mr. D. JOY observed that some delicacy of adjustment appeared to be necessary in the stud at the bottom of the force pump plunger, if it were required to open both the valves simultaneously for lowering the jack; and he enquired whether those parts of the pump had proved durable in working.

Mr. TANGYE explained that the two valves were not required to be opened at the same instant, but it was only necessary to ensure that the lower or delivery valve was opened by the stud before the suction valve. The valves and working parts, though small in size, were made very durable: their durability had been severely tested by three days' constant work, raising and lowering a weight of 3 tons three or four times in a minute continuously, which gave the jack as much work as it was likely to have to do in twelve months; and at the end of the trial all the working parts were found in as good condition as at first.

The CHAIRMAN enquired what was the weight of the small sized jack exhibited, and what load it would lift.

Mr. TANGYE said the small jack exhibited weighed 60 lbs. and was intended for lifting 4 tons load; the jack shown in the drawings weighed 150 lbs. and would lift 30 tons.

Mr. G. M. MILLER asked whether the reservoir ever wanted filling with water again, and what means there was of replenishing it.

Mr. TANGYE said that sometimes a little leakage took place if the cupped leather had been allowed to get dry by the jack standing unused for a length of time without a full supply of water; but after the leather had been soaked for a few minutes it became quite water-tight again. The reservoir was easily filled at any time through a plug hole in the jack head, or by turning the jack upside down and drawing out the ram; and when the jack was kept fully charged with water, the leather was always moist and in working order. There was

no difficulty in keeping the jacks always full of water, and they were usually supplied ready filled with water; but some jacks sent to St. Petersburg had been sent empty, to prevent any risk of the water freezing and bursting them.

Mr. G. M. MILLER enquired whether the jacks were ever worked with oil instead of water, and whether the water had to be let out of the jacks in frosty weather in this country.

Mr. TANGYE said the jacks were usually worked with water made soft with soap and oil; sometimes in winter they were filled with oil, to avoid risk of freezing in the most severe weather, but he had not heard of any instance of a jack being burst by the frost.

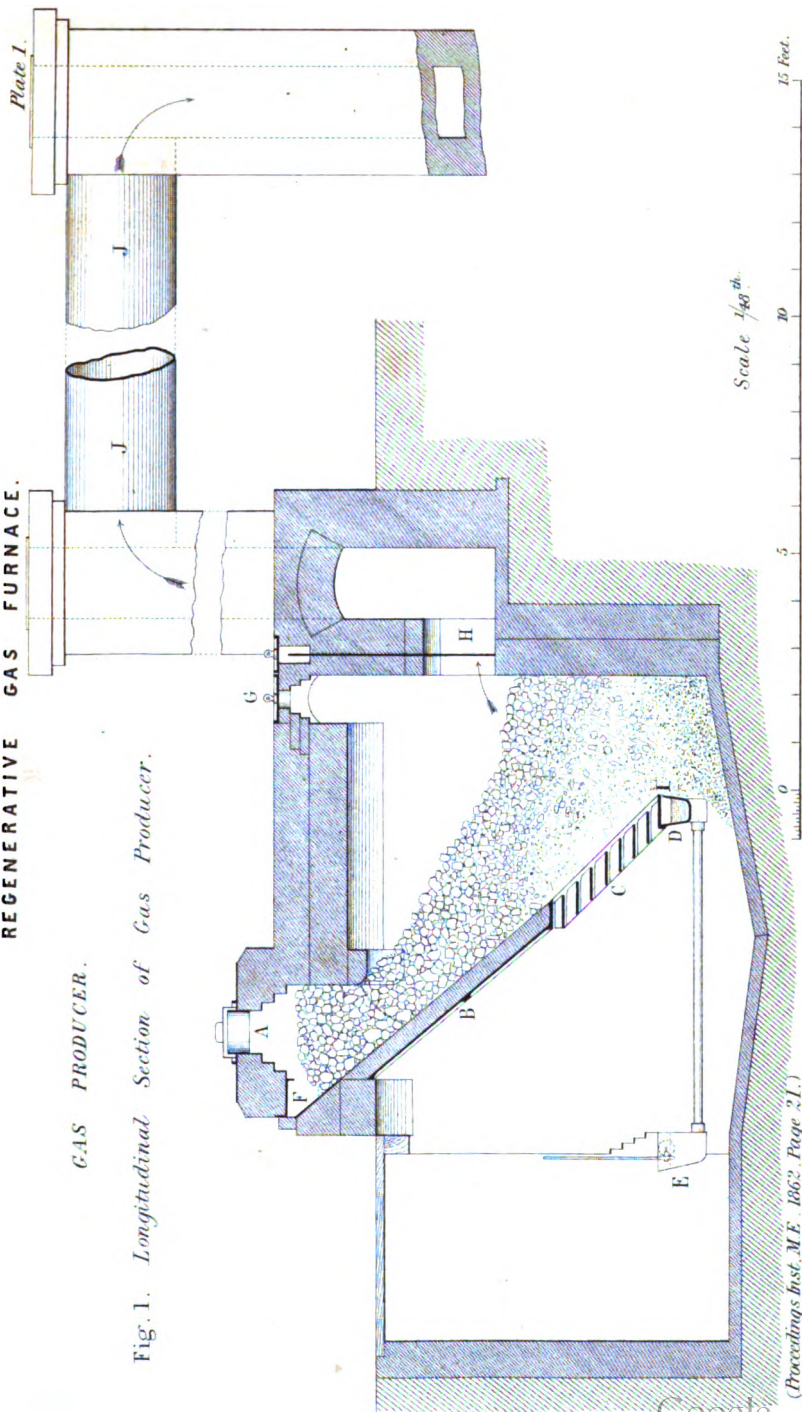
The CHAIRMAN proposed a vote of thanks to Mr. Tangye for his paper, which was passed.

The Meeting then terminated.

REGENERATIVE GAS FURNACE.

GAS PRODUCER.

Fig. 1. Longitudinal Section of Gas Producer.



(Proceedings Inst. M.E., 1862, Page 21.)

Scale $\frac{1}{48}$ in.

15 Feet.

REGENERATIVE GAS FURNACE.

GAS PRODUCER.

Fig. 2. Front Elevation

and Transverse Section
at front.

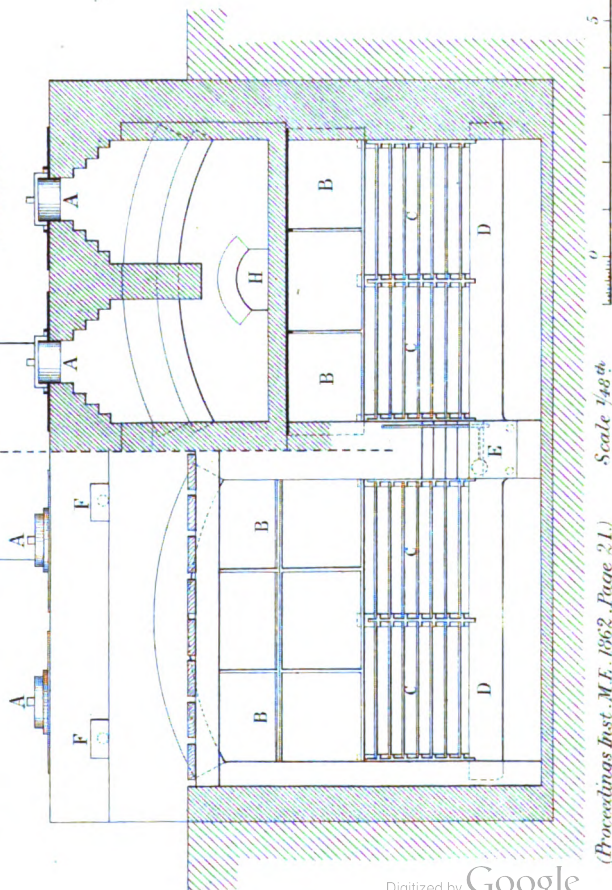
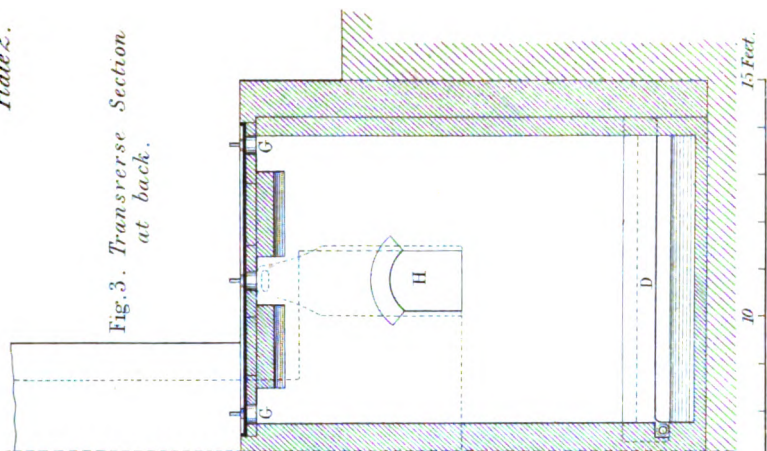


Plate 2.

Fig. 3. Transverse Section
at back.



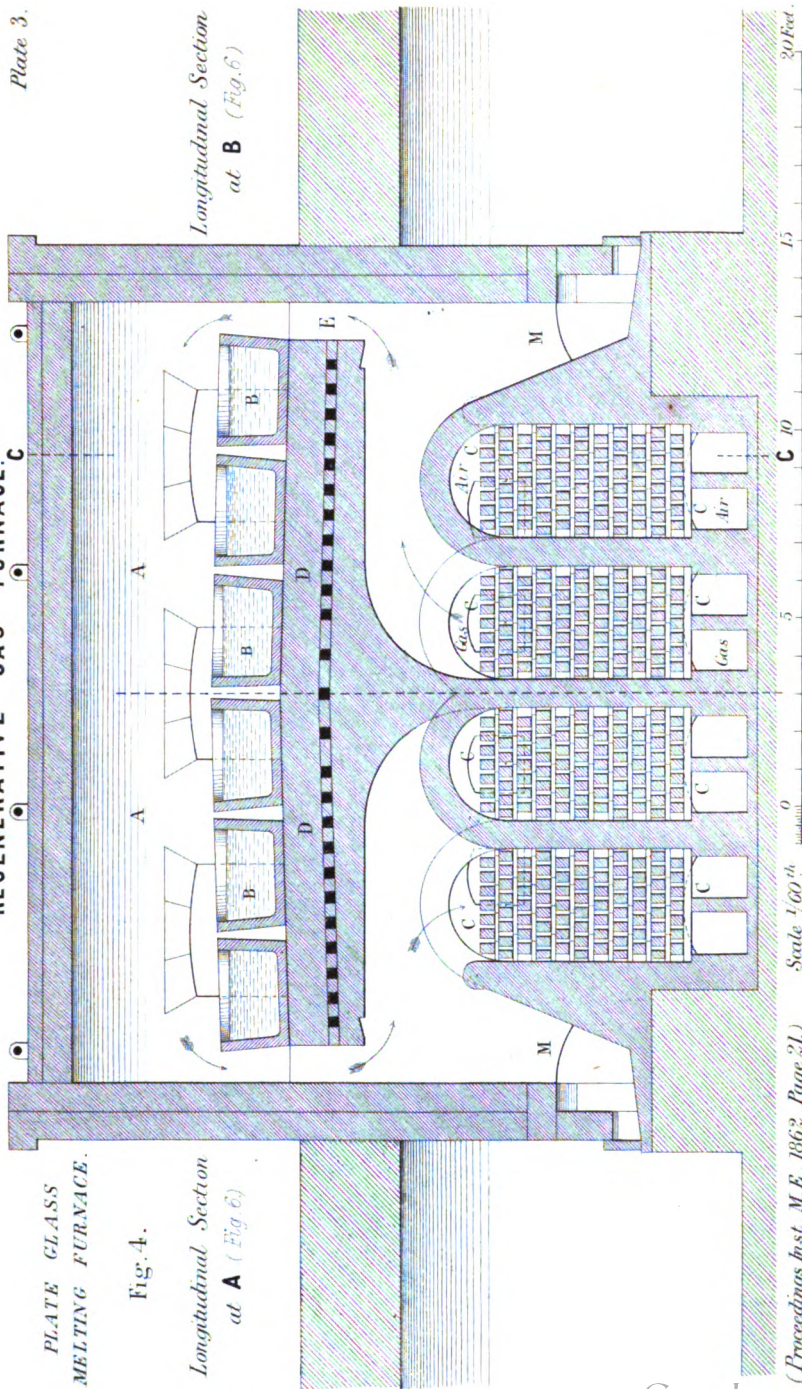
REGENERATIVE GAS FURNACE. C

PLATE GLASS
MELTING FURNACE.

Fig. 4.

Longitudinal Section
at A (Fig 6)

Longitudinal Section
at B (Fig. 6)

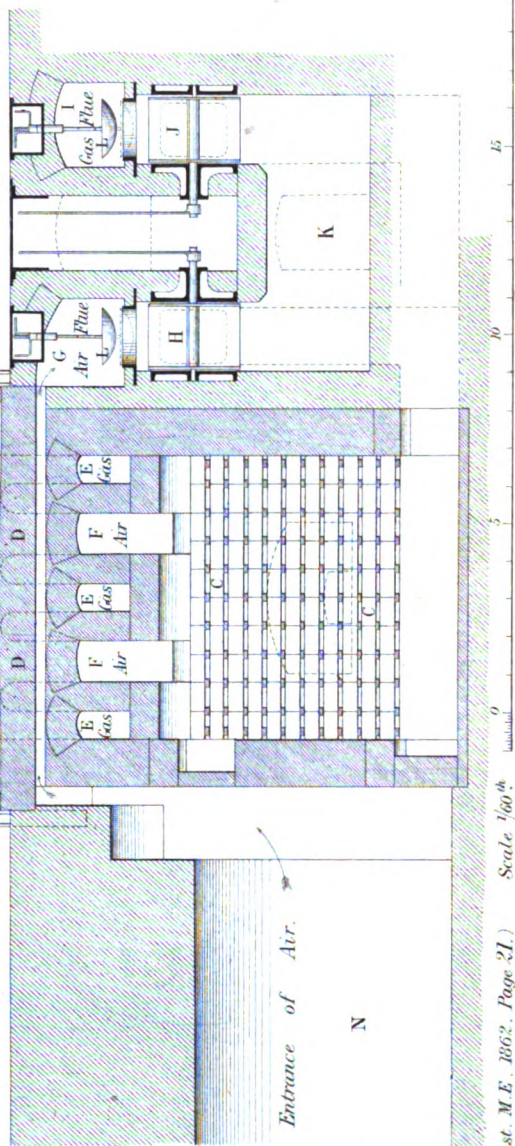


REGENERATIVE GAS FURNACE.

PLATE GLASS MELTING FURNACE.

Fig. 5.

Transverse Section at **CC** (Fig. 4.)



Entrance of Air.

N

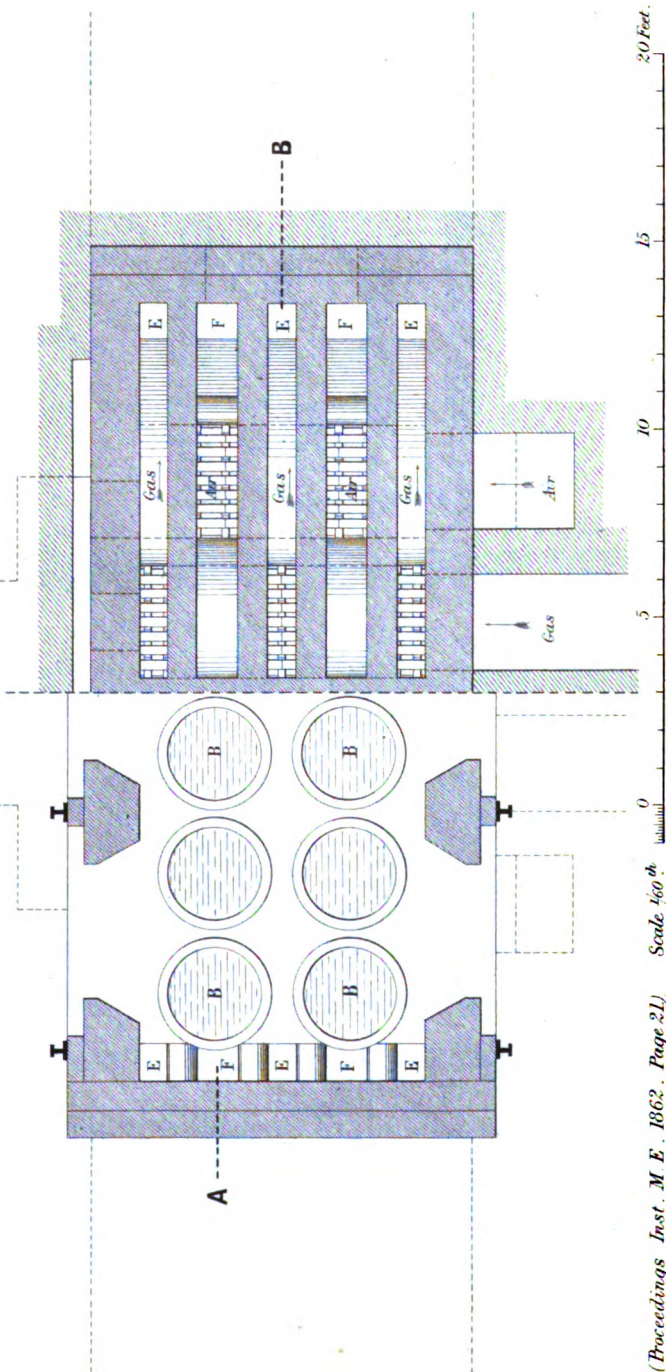
**REGENERATIVE GAS FURNACE.
PLATE GLASS MELTING FURNACE.**

Plate 5.

Sectional Plan above siege.

Sectional Plan below siege.

Fig. 6.



Scale 1/60th

(Proceedings Inst. M.E., 1862, Page 21.)

PLATE GLASS

MELTING FURNACE.

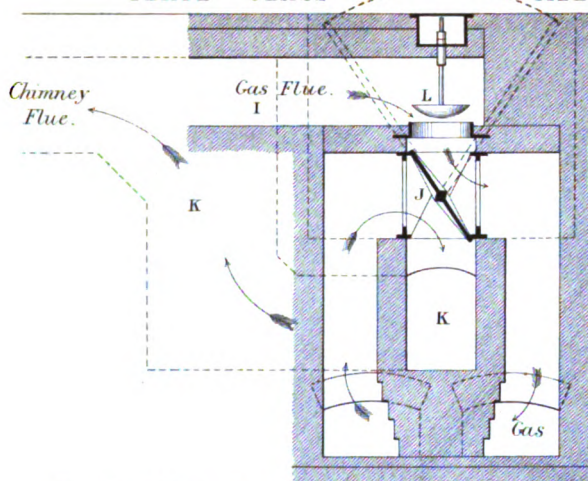


Fig. 7.
Vertical Section
of Gas Valve.

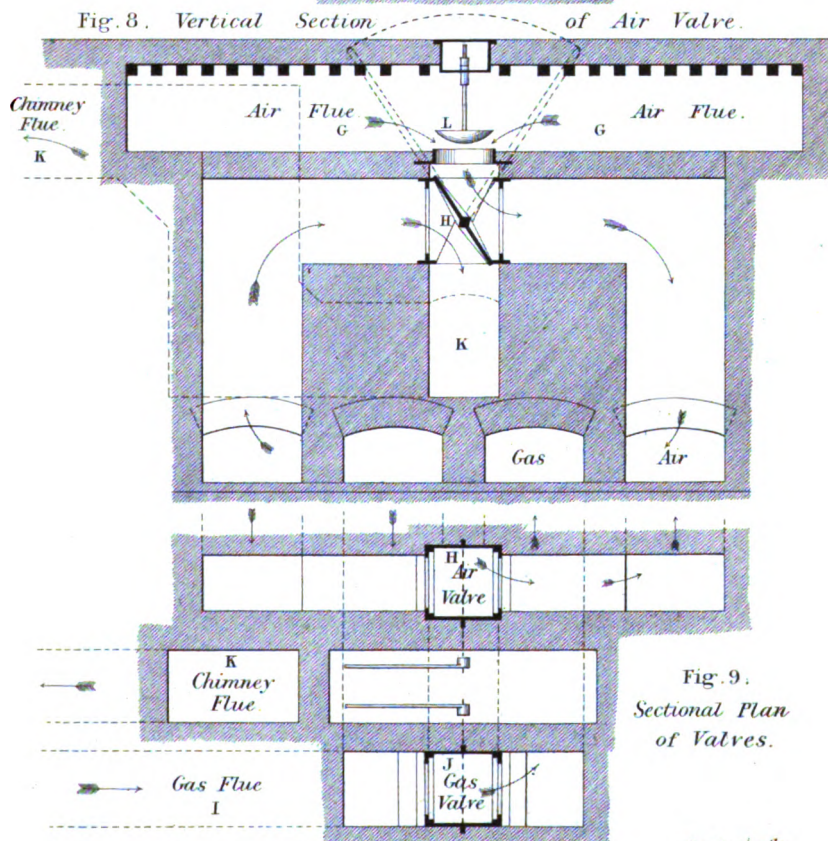


Fig. 8. Vertical Section
of Air Valve.

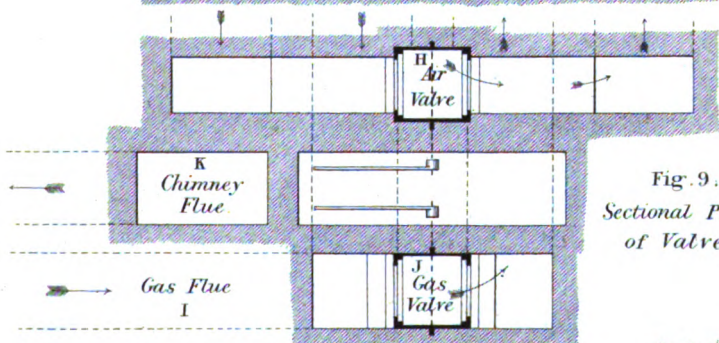


Fig. 9.
Sectional Plan
of Valves.

REGENERATIVE GAS FURNACE.

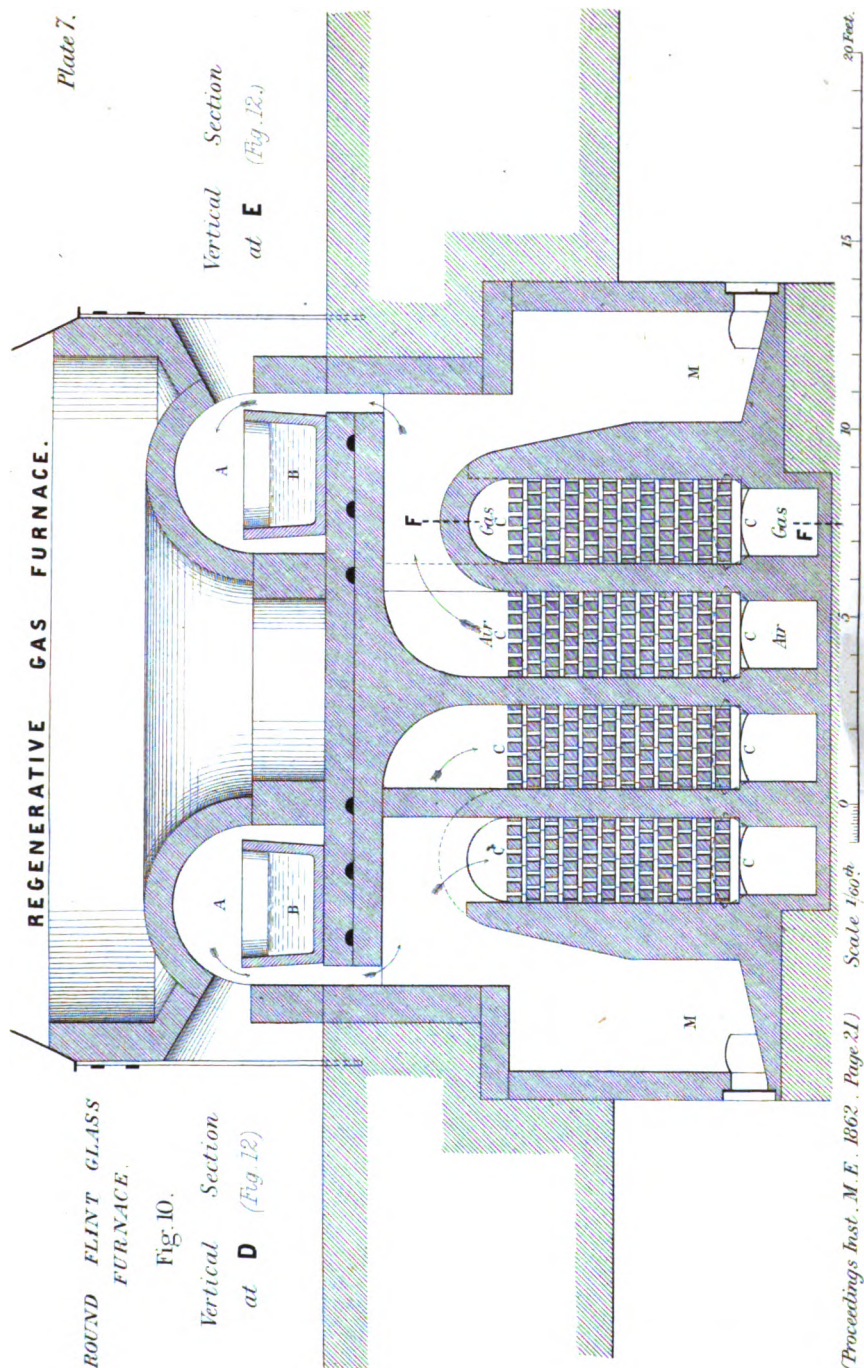
Plate 7.

ROUND FLINT GLASS
FURNACE.

Fig. 10.

Vertical Section
at **D** (Fig 12)

Vertical Section
at **E** (Fig 12.)

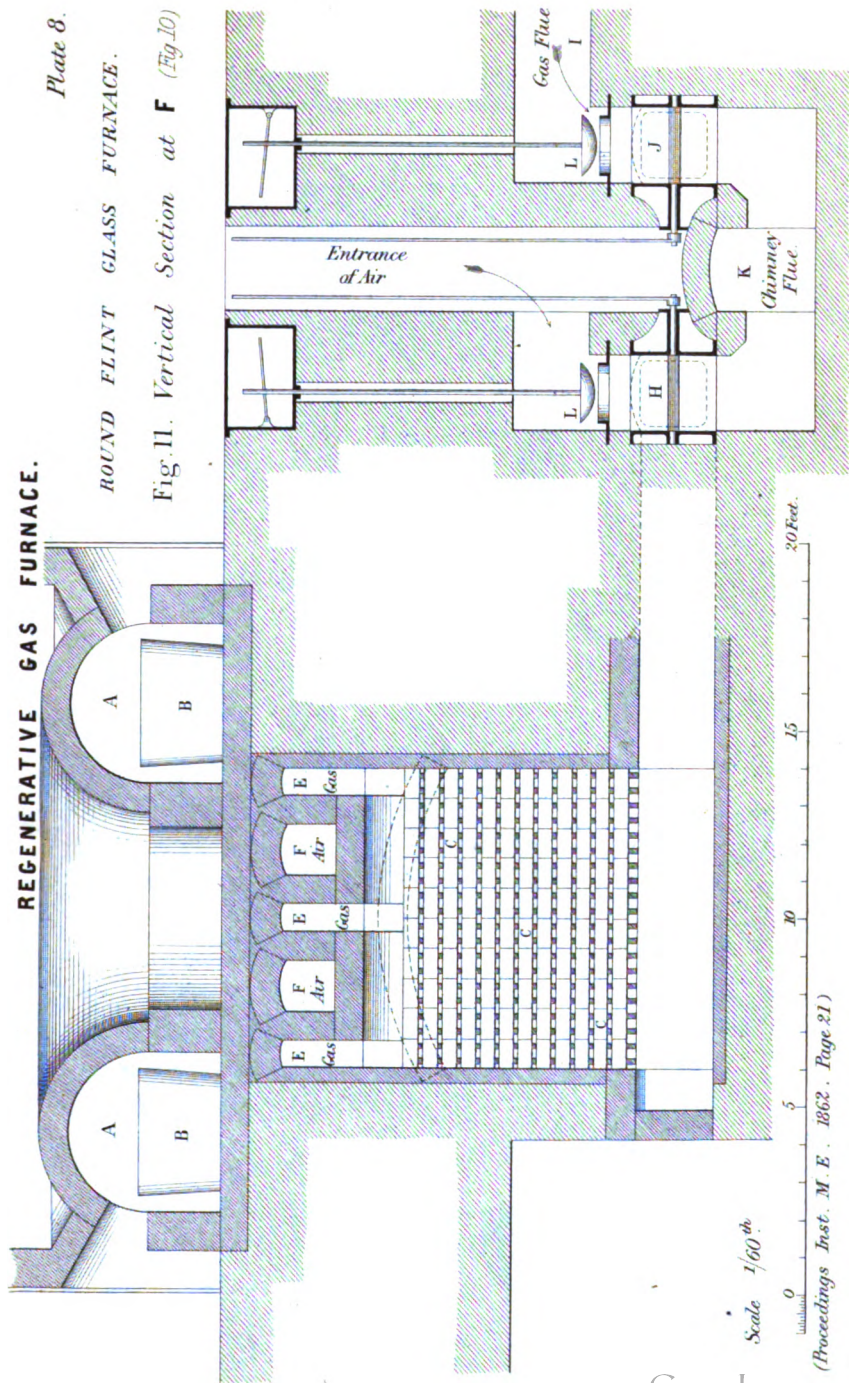


REGENERATIVE GAS FURNACE.

Plate 8.

ROUND FLINT GLASS FURNACE.

Fig. 11. Vertical Section at F (Fig 10)



Scale 1/60th

0 5 10 15 20 Feet.

(Proceedings Inst. M. E. 1862. Page 21)

REGENERATIVE GAS FURNACE.

ROUND FLINT GLASS FURNACE.

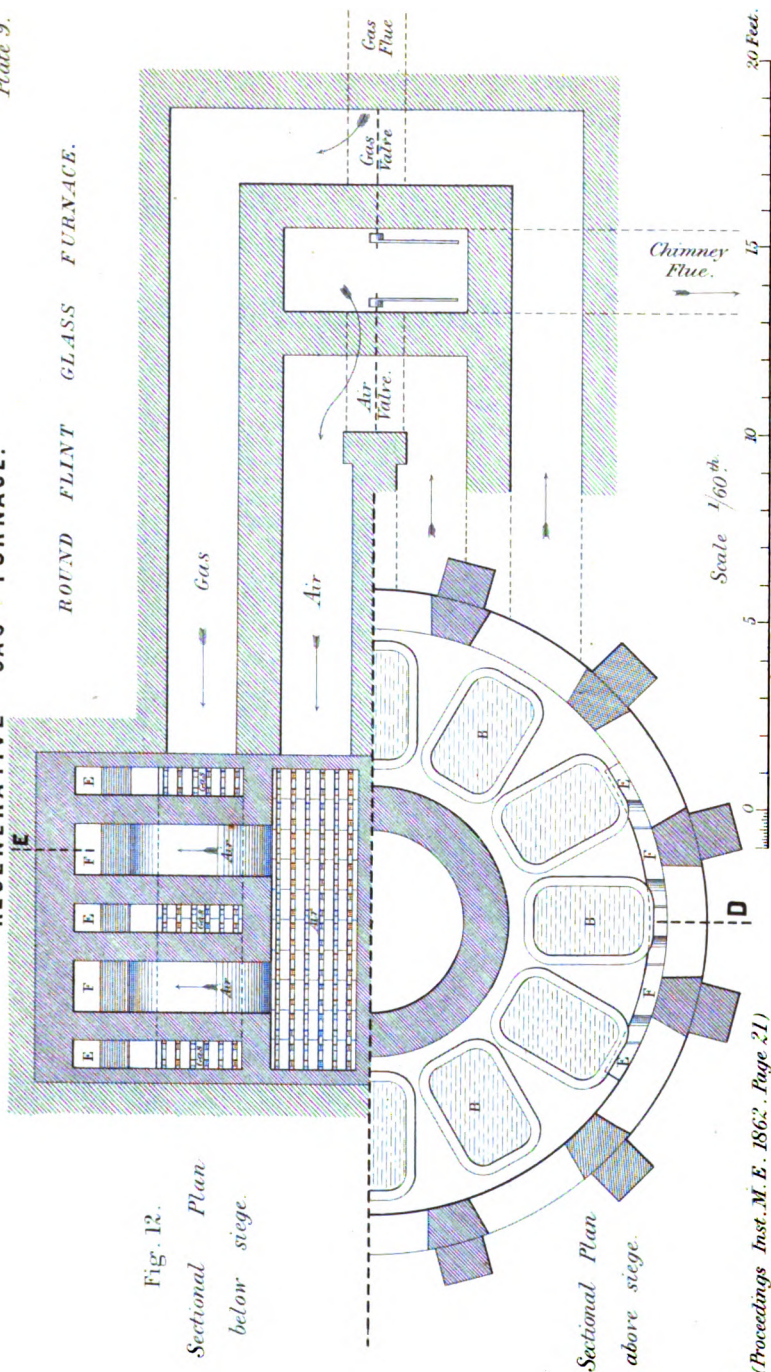


Fig. 12.
Sectional Plan
below siege.

Sectional Plan
above siege.

PUDDLING FURNACE.

Fig. 13. Longitudinal Section.

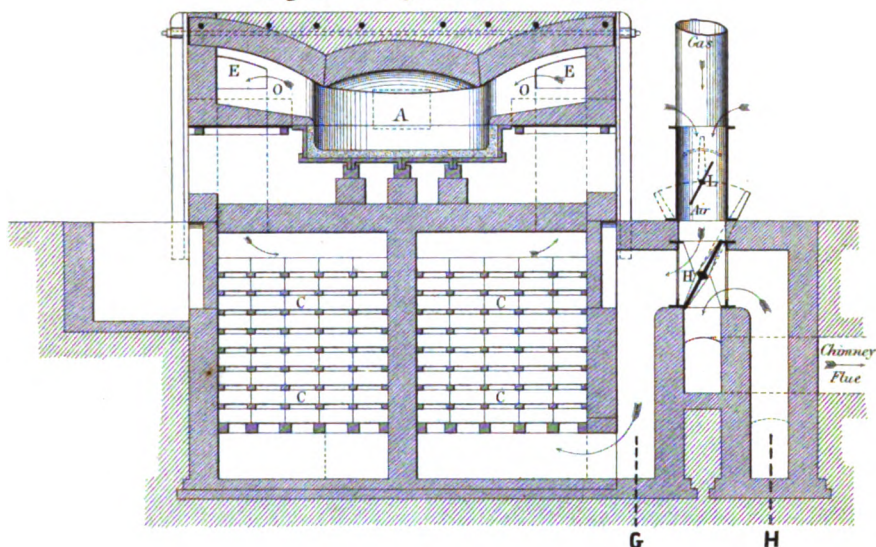


Fig. 14. Sectional Plan of Puddling Chamber.

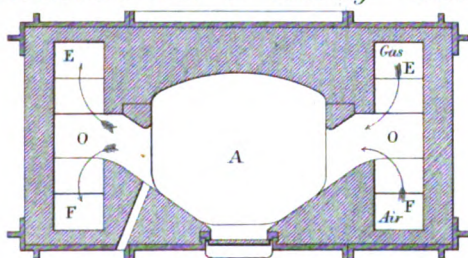
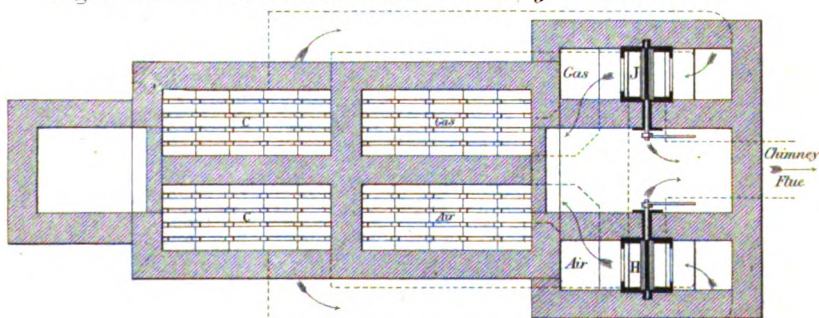


Fig. 15. Sectional Plan below Puddling Chamber.



(Proceedings Inst. M.E. 1862. Page 21)

Scale $\frac{1}{60}^{\text{th}}$

20 Feet.

PUDDLING FURNACE.

Fig.16. Transverse Section through mixing chamber O.

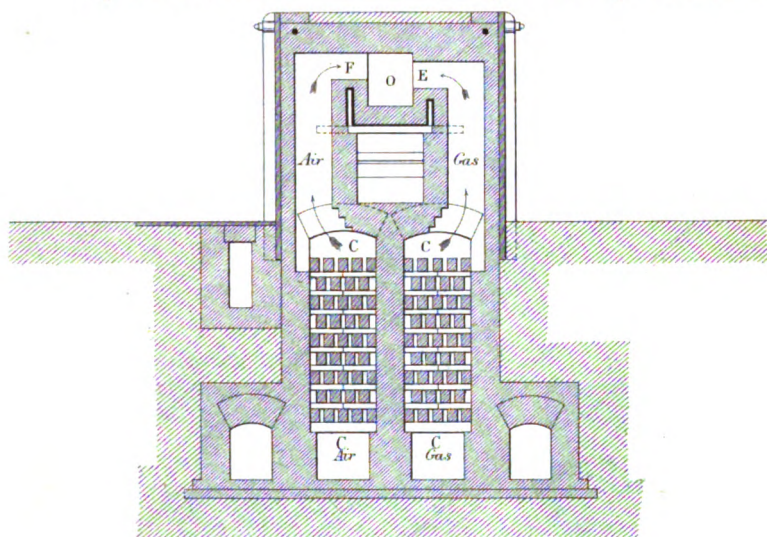


Fig. 17.
Vertical Section at G (Fig 13)

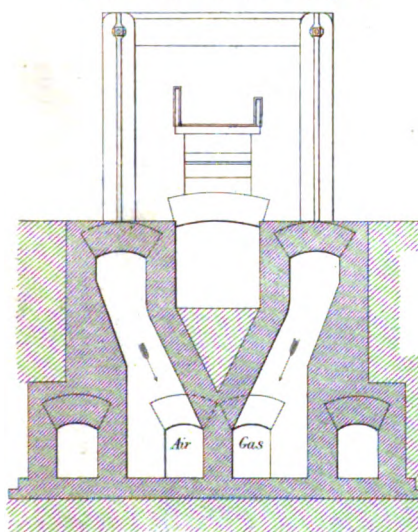
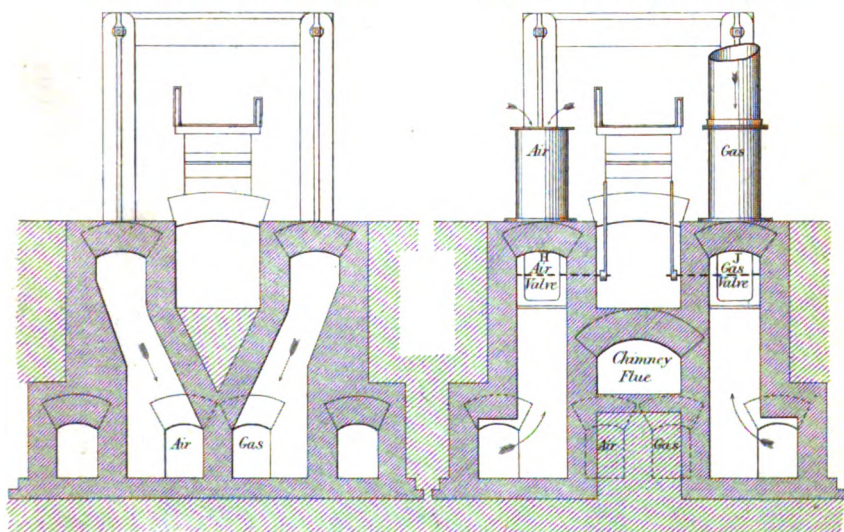


Fig. 18.
Vertical Section at H (Fig 13)



Scale $\frac{1}{60}^{th}$.

0 5 10 15 20 Feet.

(Proceedings Inst. M.E. 1862. Page 21.)

REGENERATIVE GAS FURNACE. STEEL MELTING FURNACE.

Fig. 19 . Longitudinal Section.

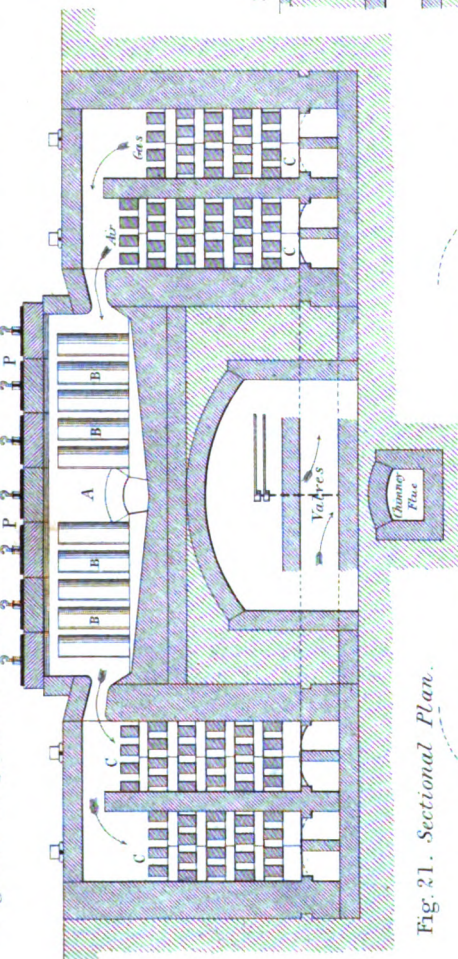


Fig. 21. Sectional Plan.

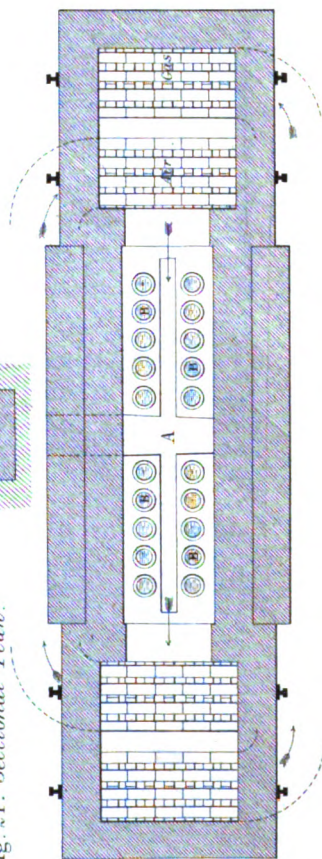
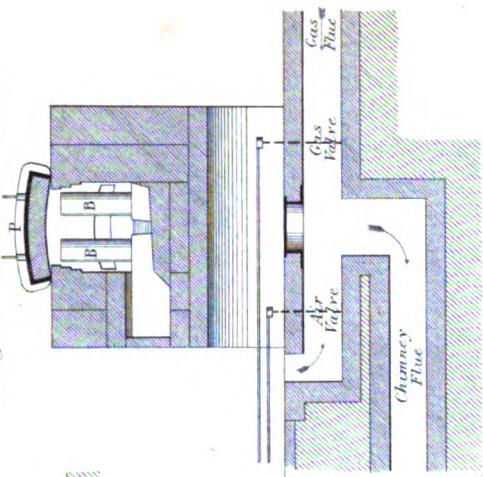
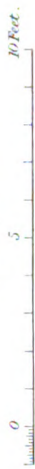


Fig. 20. Transverse Section.



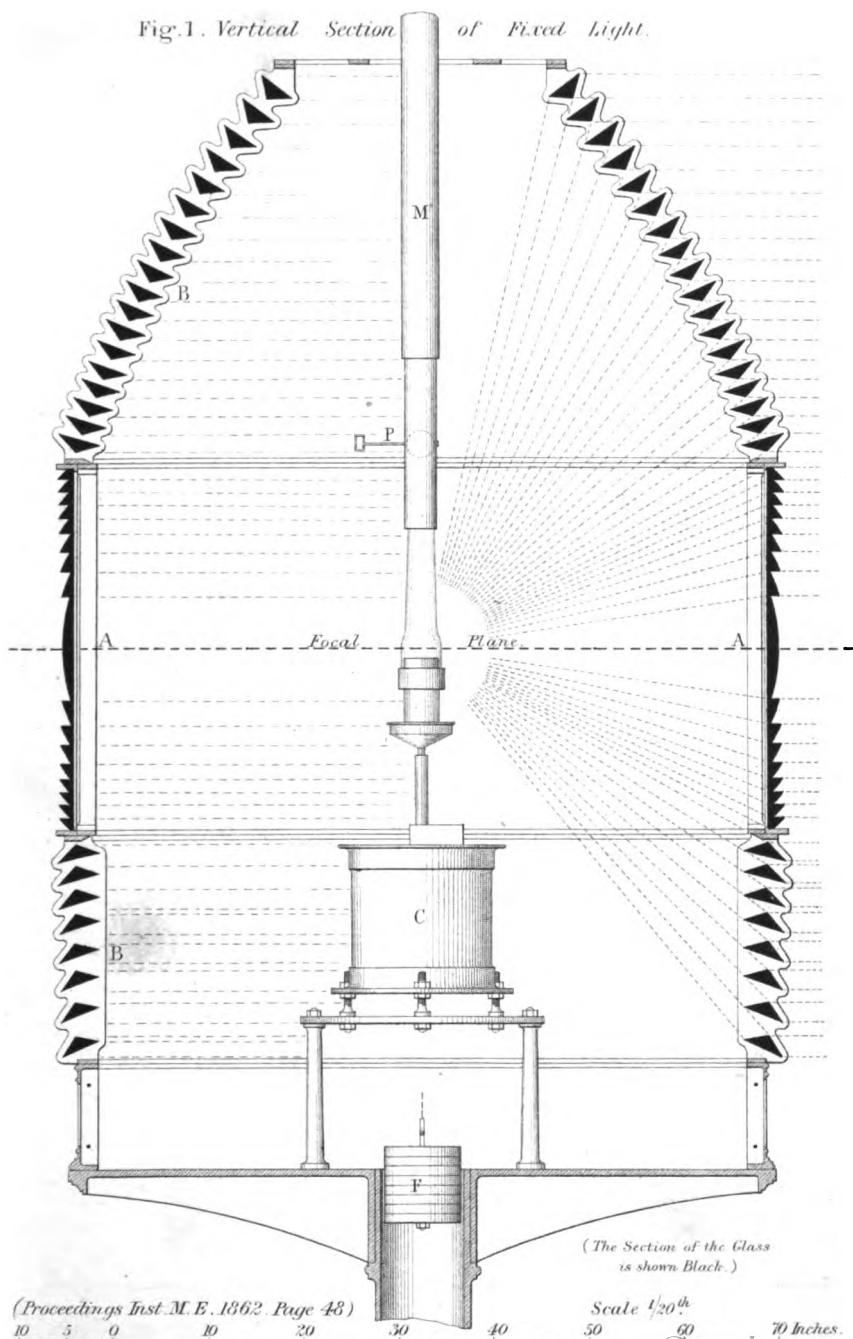
Scale 1/60th



LIGHTHOUSE APPARATUS.

Plate B.

Fig.1. Vertical Section of Fixed Light.



(Proceedings Inst. M. E. 1862. Page 48)

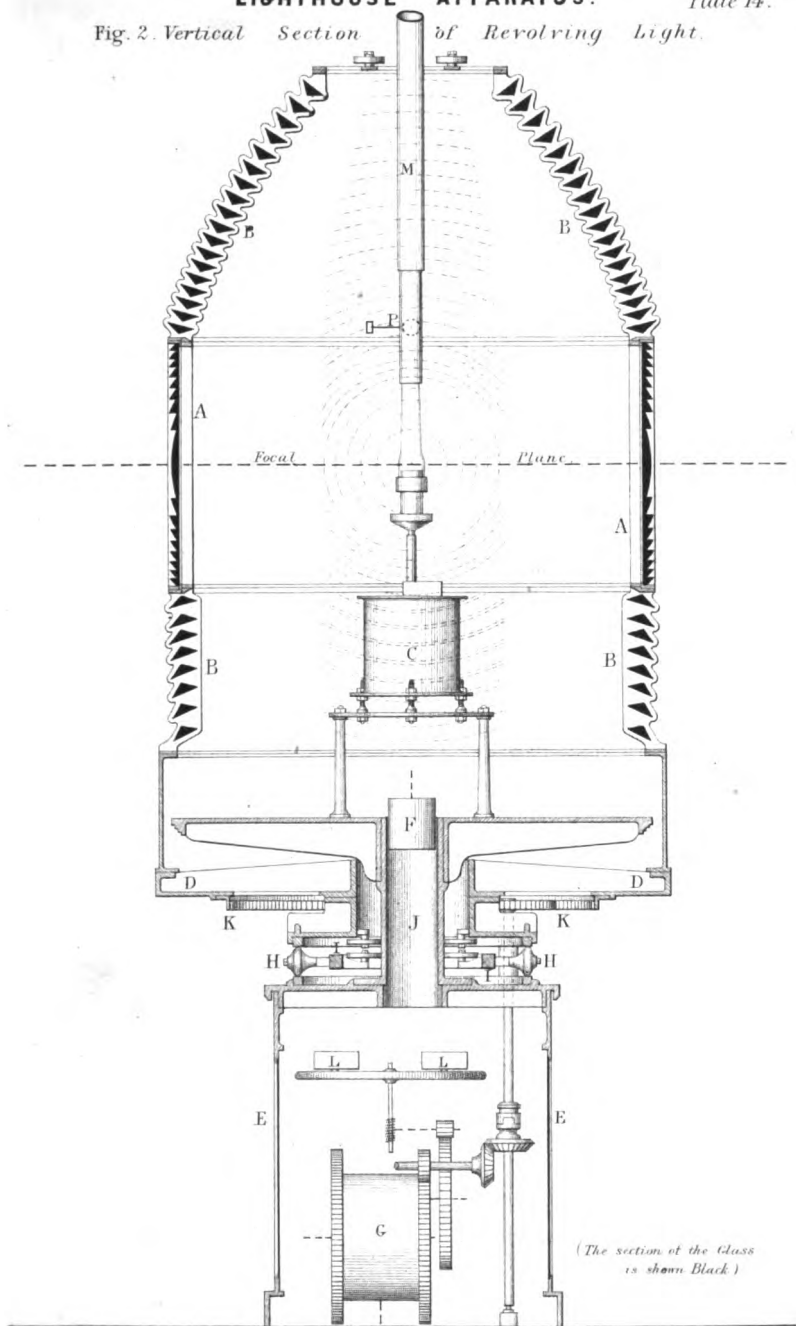
Scale $\frac{1}{20}^{th}$
10 5 0 10 20 30 40 50 60 70 inches.

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LIGHTHOUSE APPARATUS.

Plate 14.

Fig. 2. Vertical Section of Revolving Light.



LIGHTHOUSE APPARATUS.

Plate E.

Fig. 3. Plan of Fixed Light.

Scale $1/20^{\text{th}}$

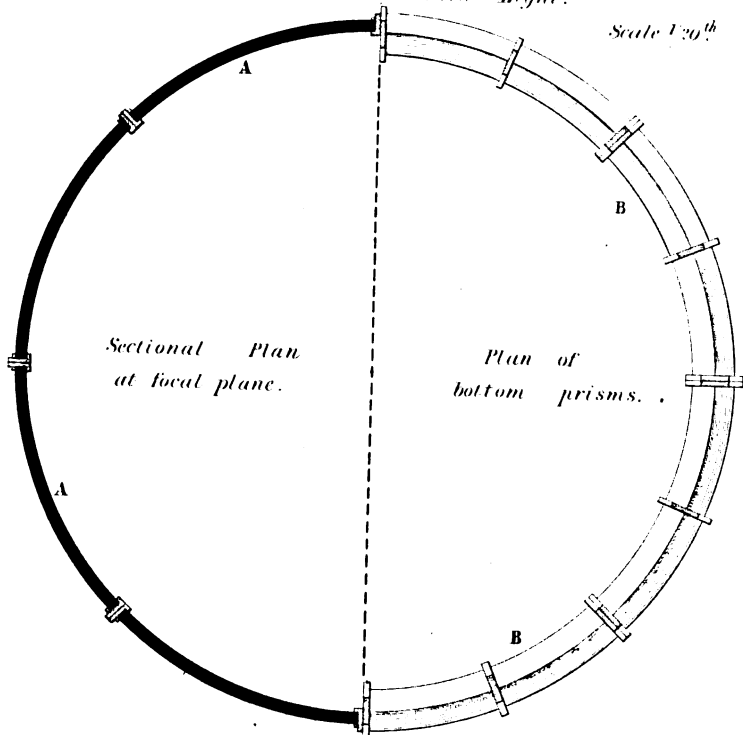


Fig. 4. Plan of Revolving Light.

Scale $1/50^{\text{th}}$

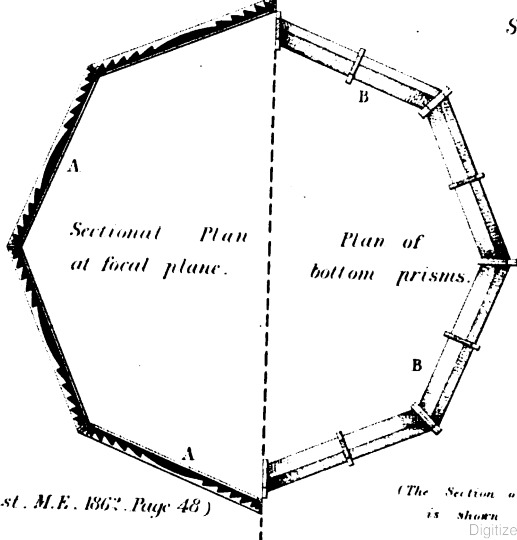


Fig. 5.
Vertical
Section
of Lamp.

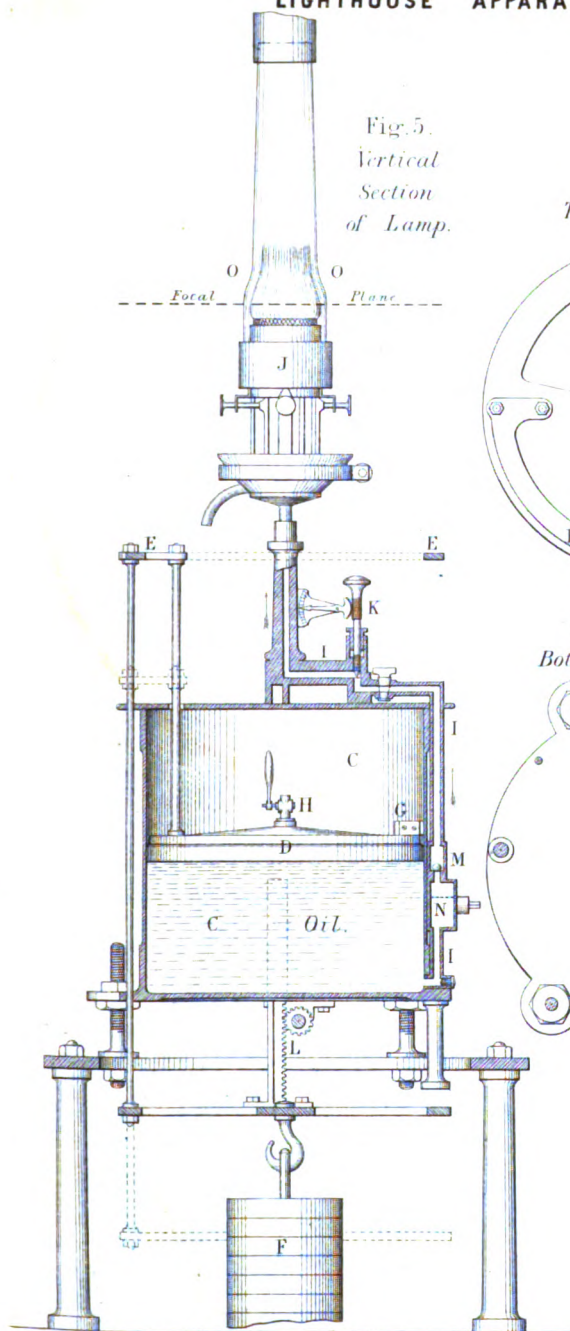


Fig. 6. Plan of
Top of Cylinder.

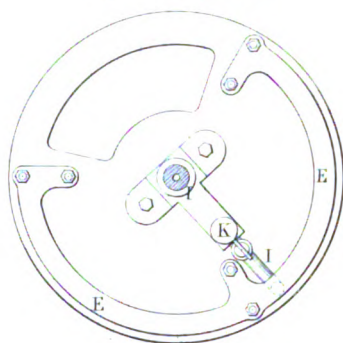


Fig. 7. Plan of
Bottom of Cylinder.

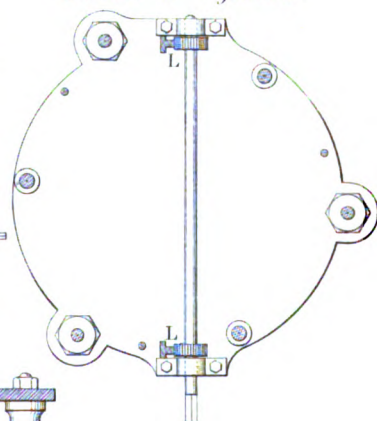
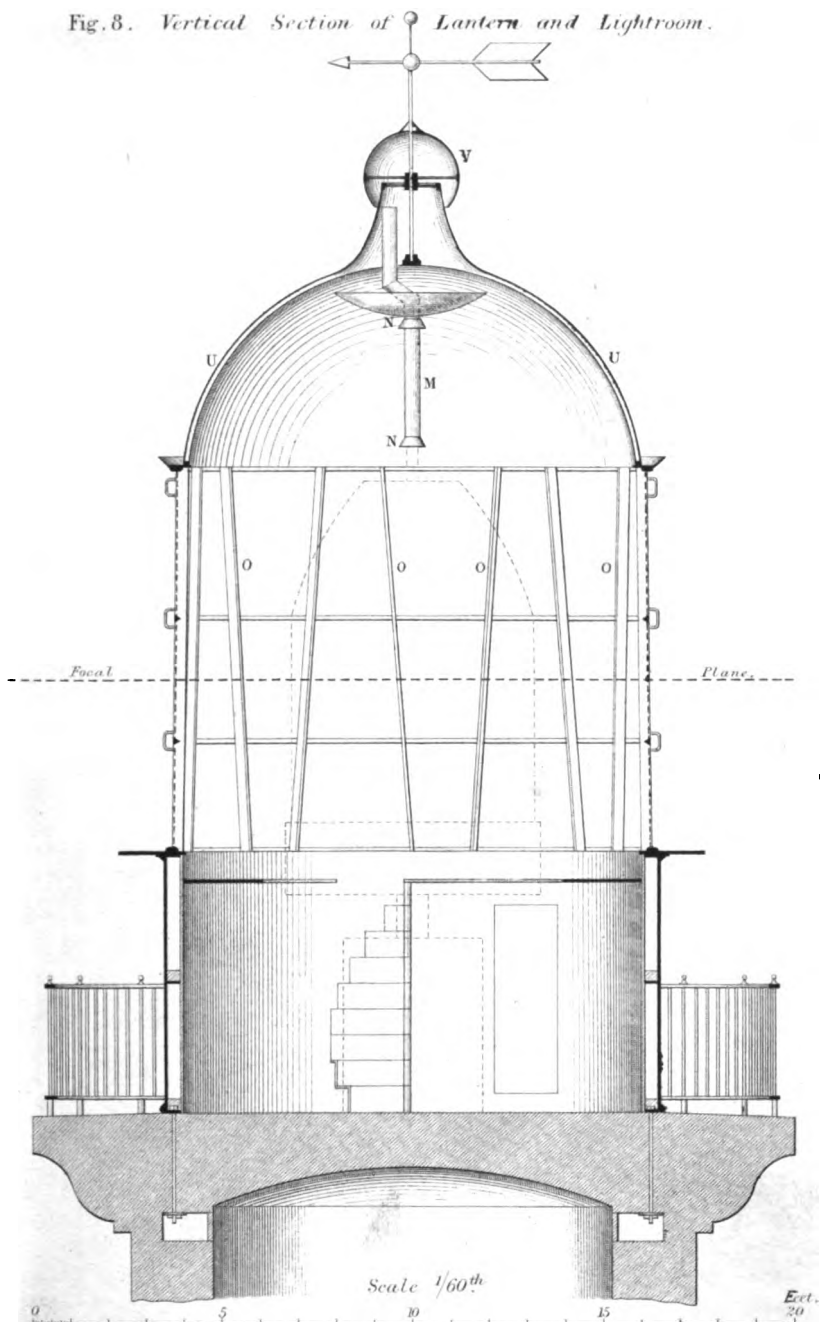


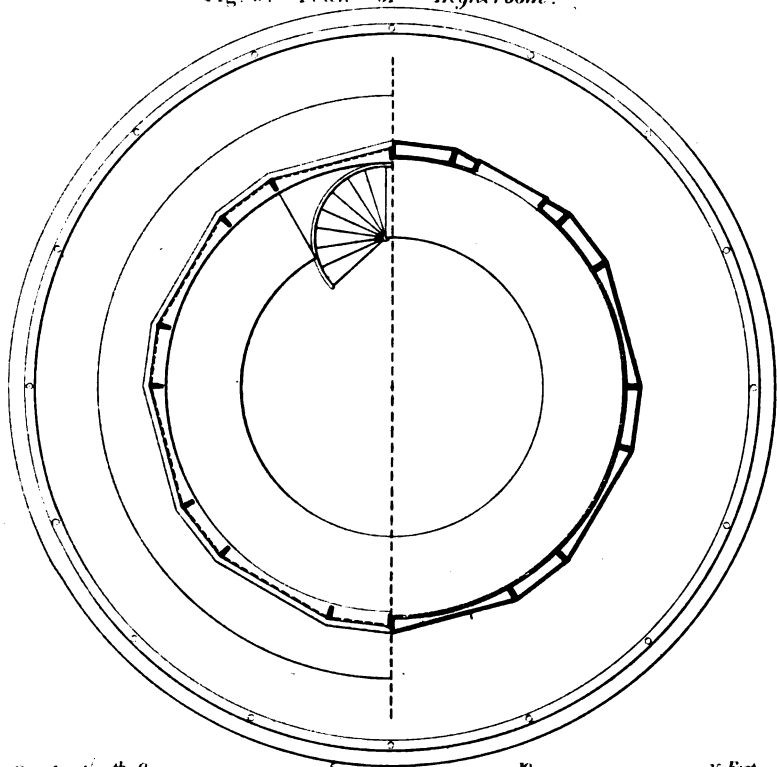
Fig. 8. Vertical Section of Lantern and Lightroom.



LIGHTHOUSE APPARATUS.

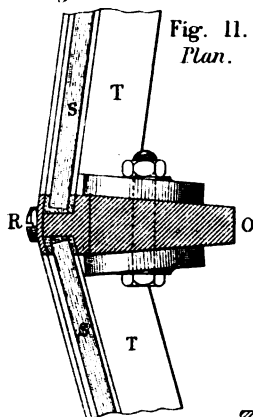
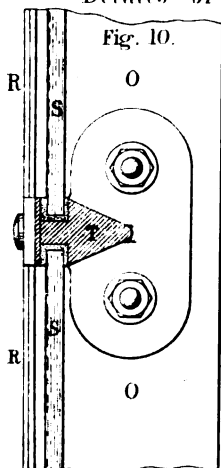
Plate 18.

Fig. 9. *Plan of Lightroom.*

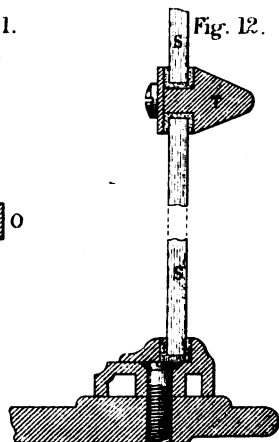


Scale $\frac{1}{60}^{th}$ 0 5 10 15 Feet.

Details of Glazing and Framework of Lantern.



Scale $\frac{1}{4}^{th}$



0 1 2 3 4 5 Inches.

(*Proceedings Inst. M. E. 1862. Page 48.*)

Fig.1. General Plan of South Yorkshire Coalfield.

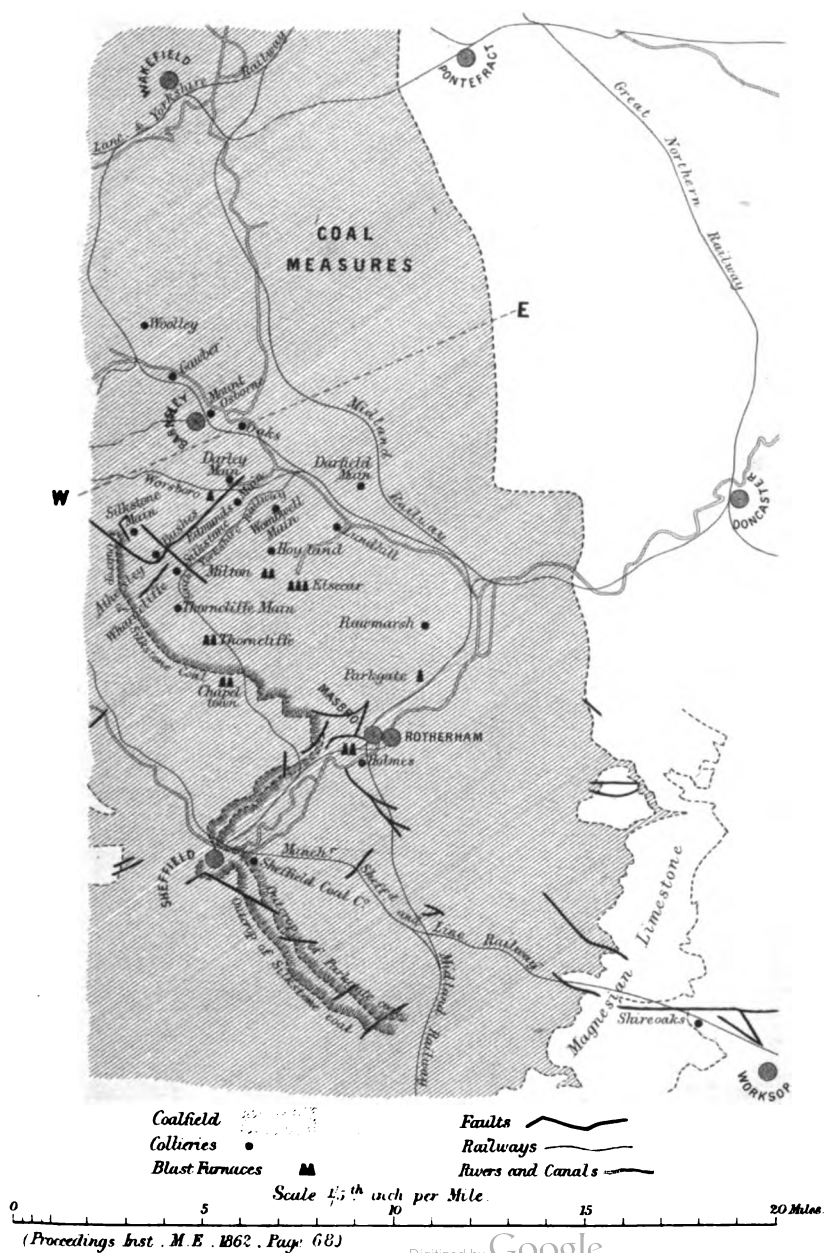
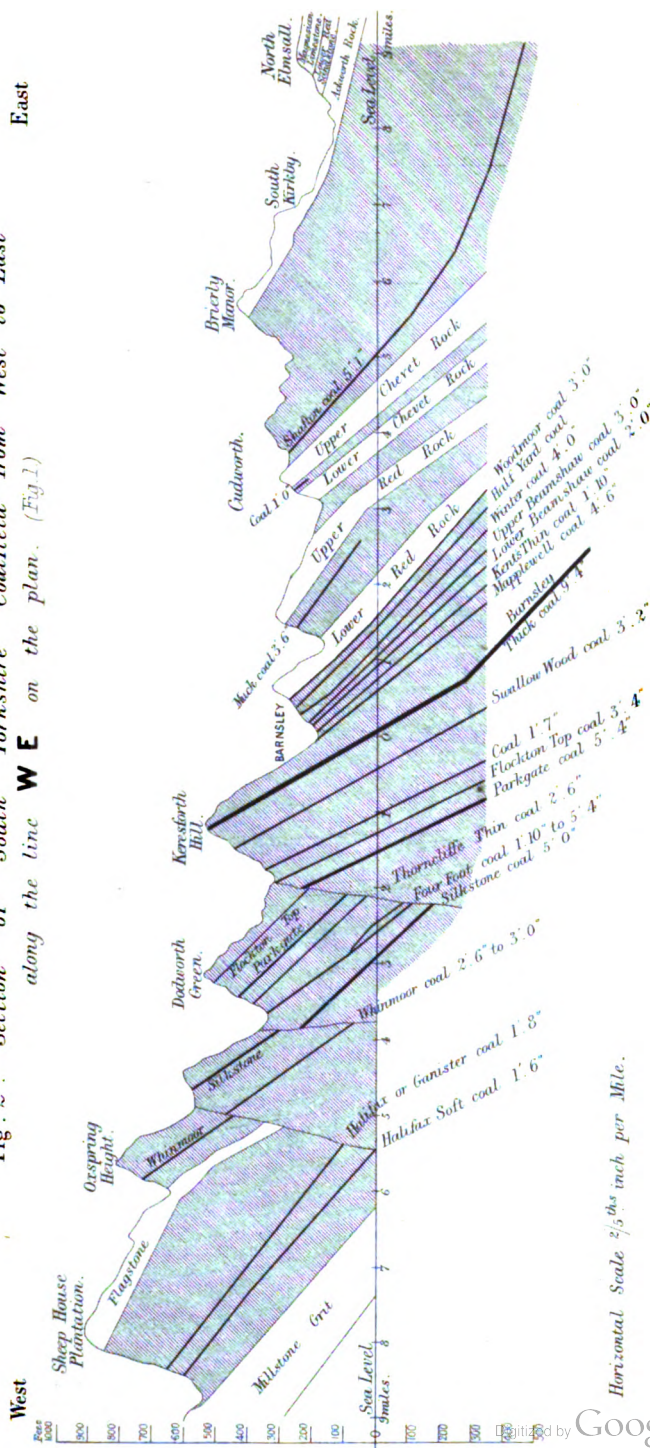


Fig. 2. Section of South Yorkshire Coalfield from West to East along the line **WE** on the plan. (Fig 1.)



Horizontal Scale $\frac{2}{3}$ inch per Mile.

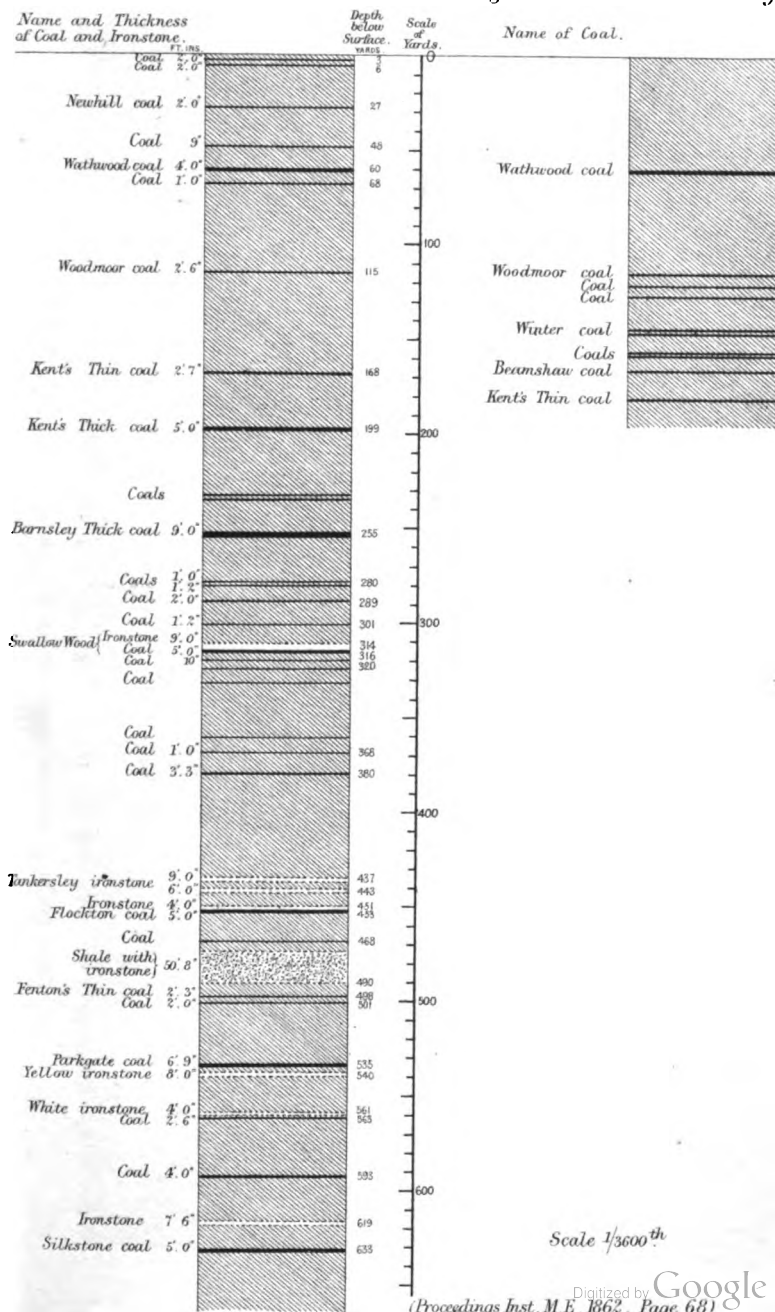
SOUTH YORKSHIRE COAL MINING.

Plate 21.

Vertical Section of Strata in South Yorkshire Coalfield.

Fig. 3. At Wath Wood.

Fig. 4. At the Oaks Colliery.



SOUTH YORKSHIRE COAL MINING.

Plate 22.

Fig. 5. Plan of *Narrow Work*, on the *End of the coal*.

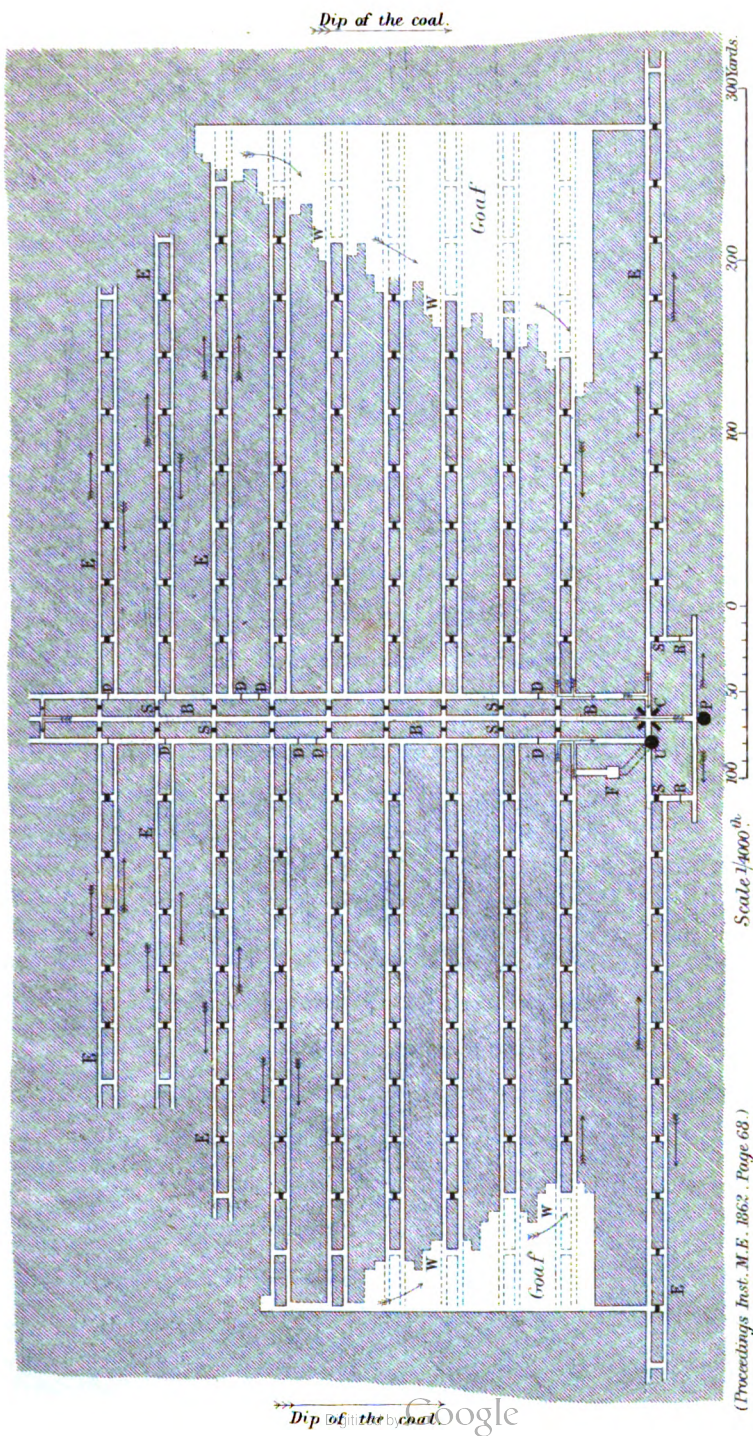


Fig. 6. Plan of Long Work.
First mode.

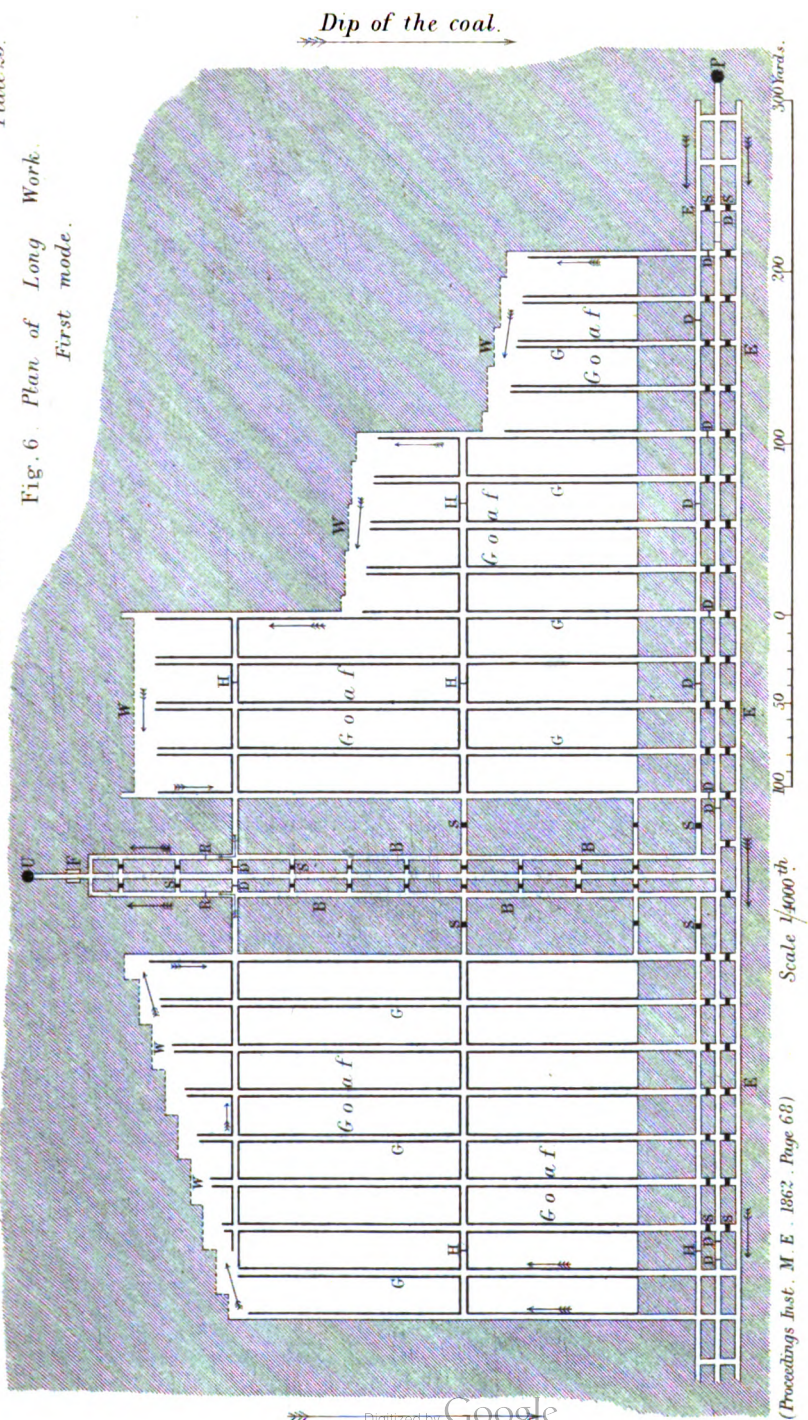


Fig. 7. Plan of Long Work.
Second mode

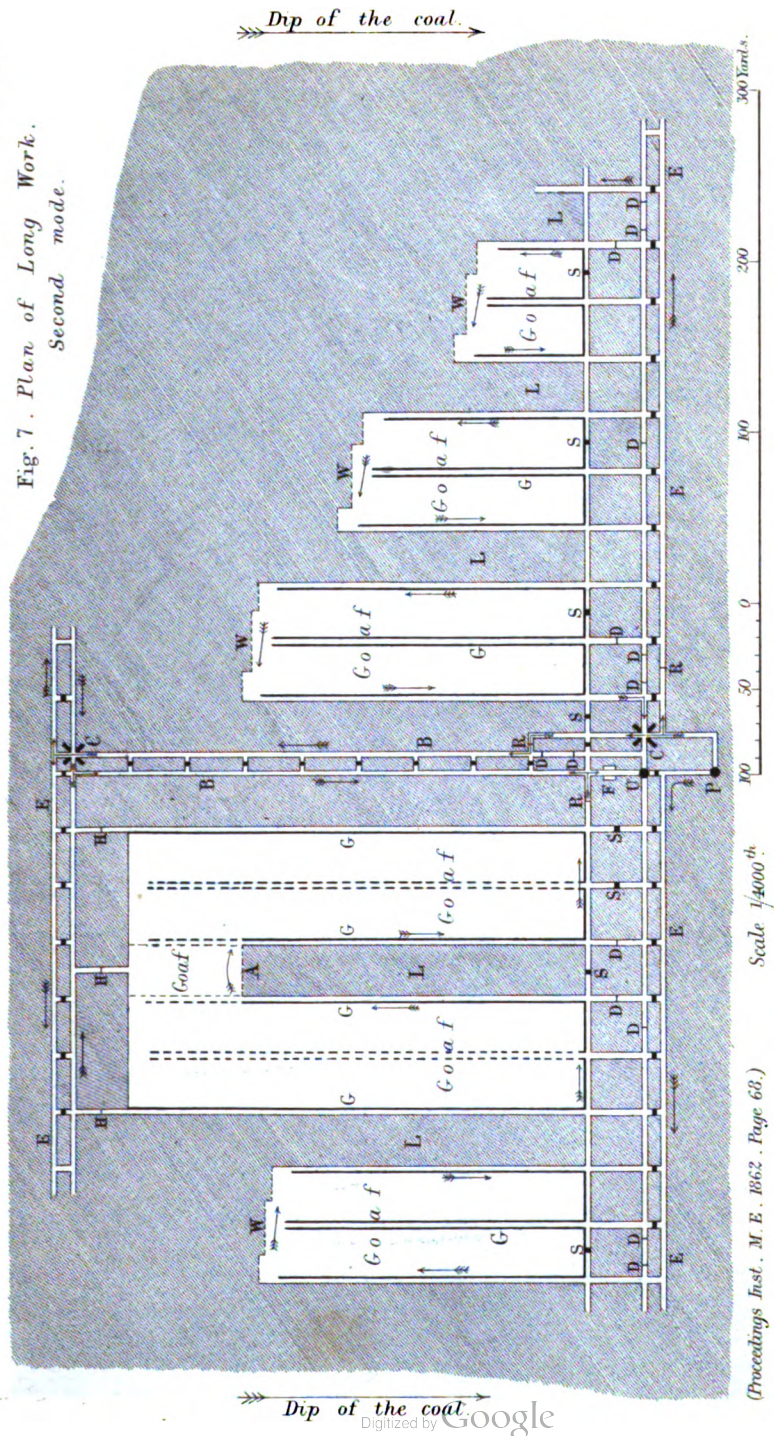


Fig. 8. Plan of Bords and Long Work.

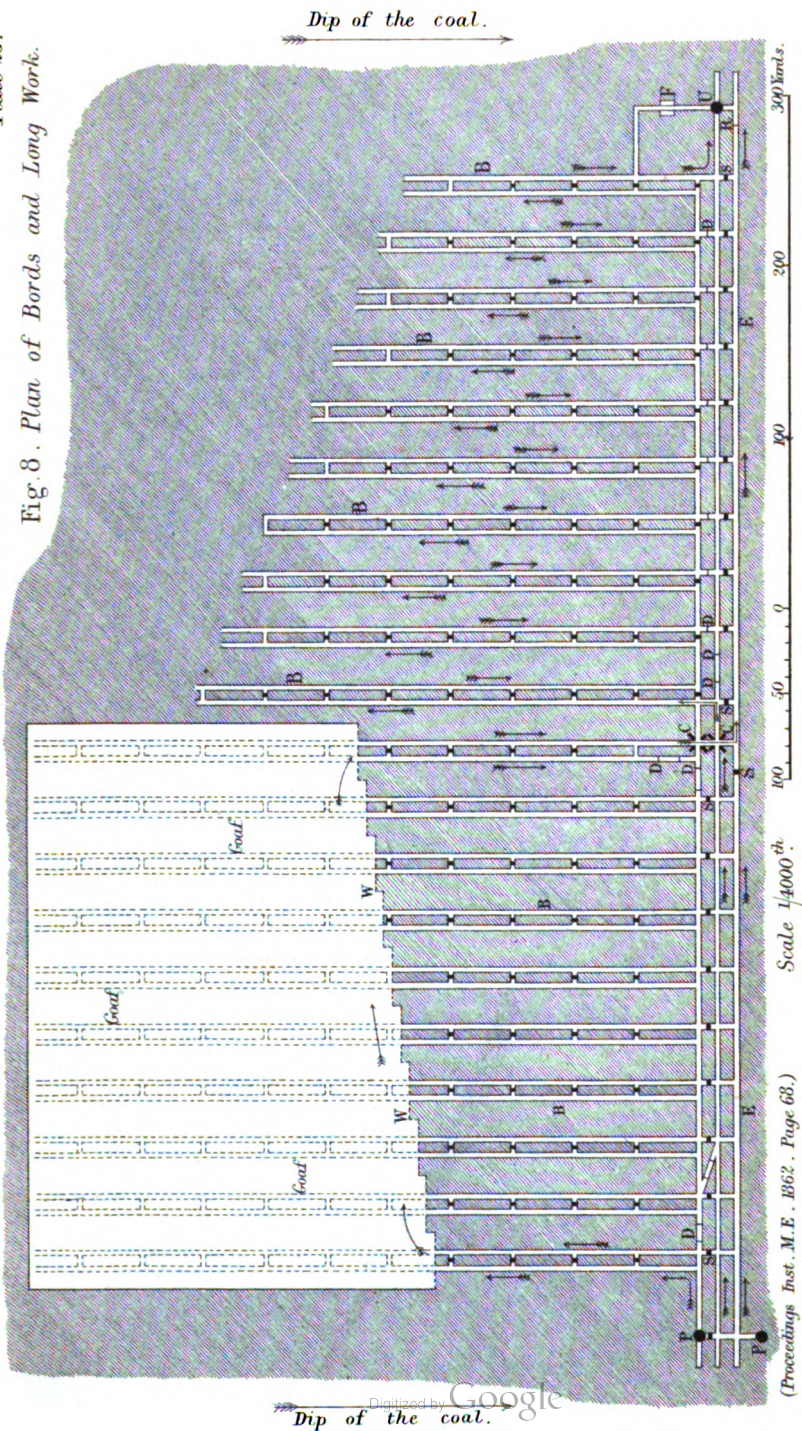


Fig. 9. Plan of Wide Work.

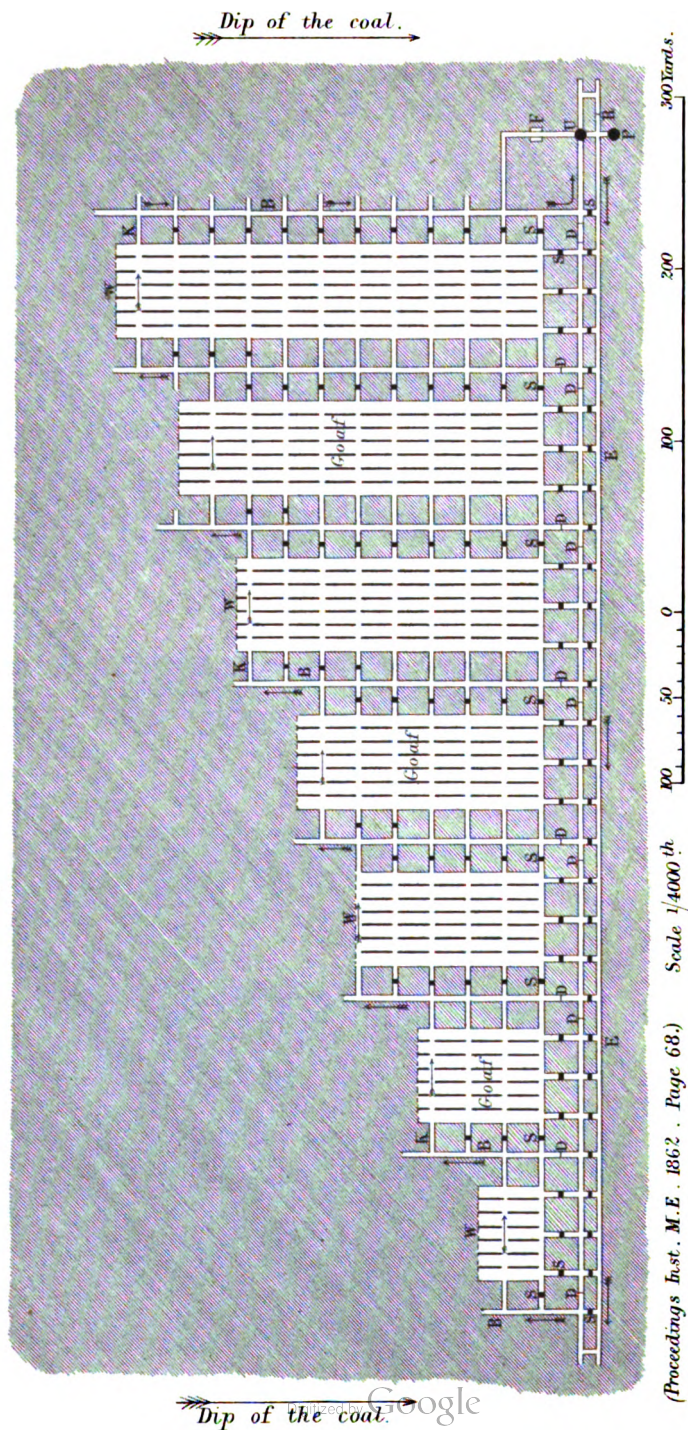
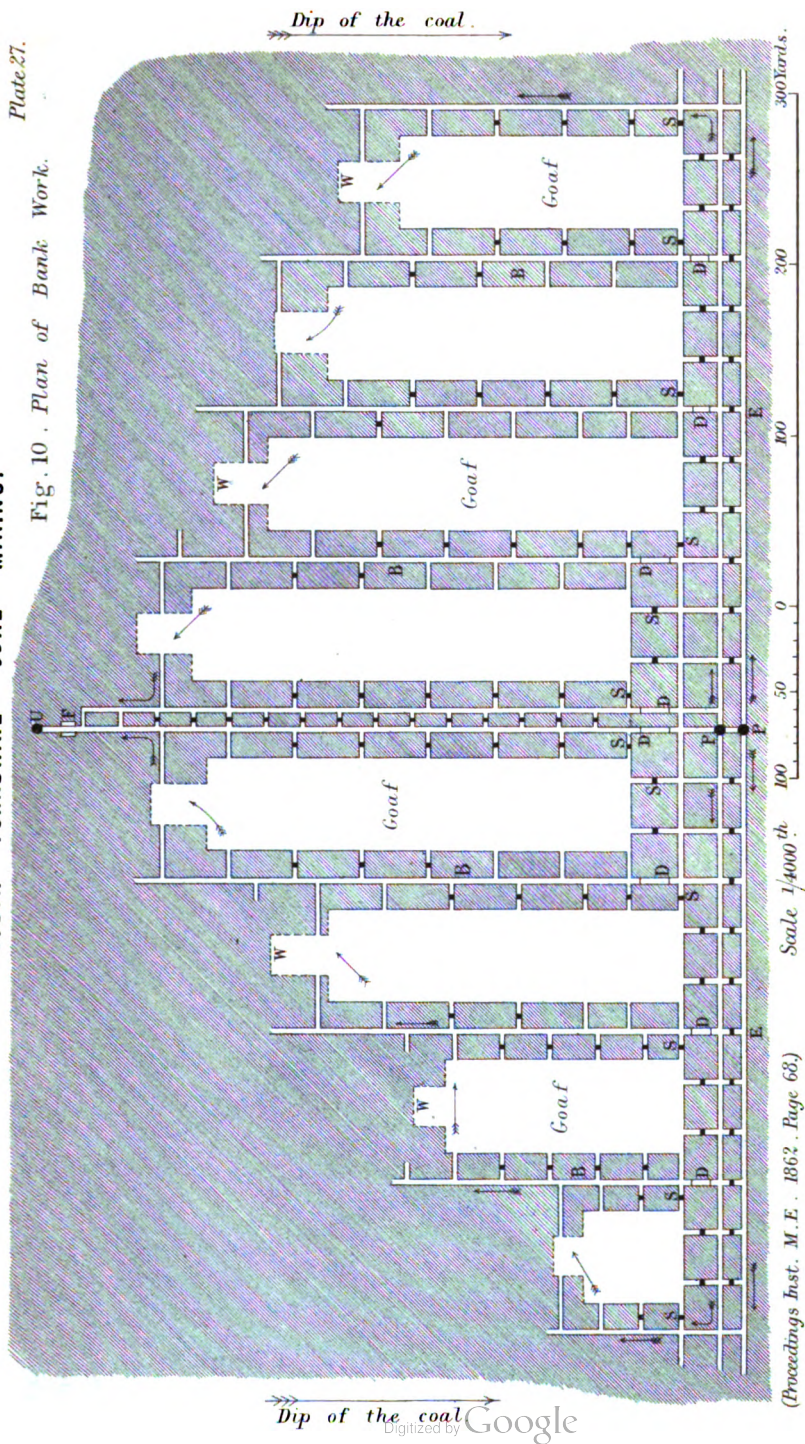


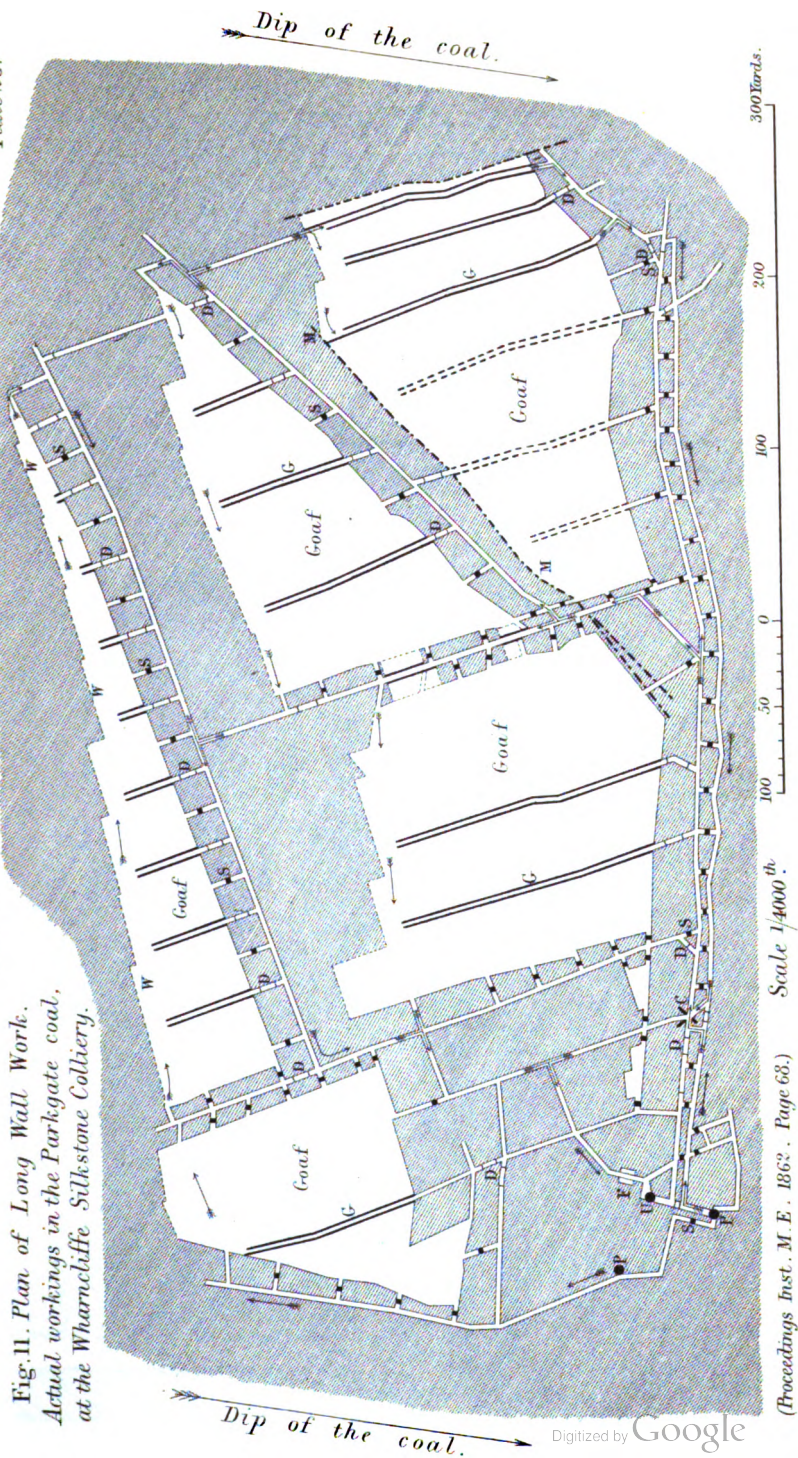
Fig. 10. Plan of Bank Work.



SOUTH YORKSHIRE COAL MINING.

Plate 28.

Fig. 11. Plan of Long Wall Work.
Actual workings in the Parkgate coal,
at the Wharfedale Silkstone Colliery.



(Proceedings Inst. M.E., 1862, Page 68.)

SOUTH YORKSHIRE COAL MINING.

Fig. 12. Longitudinal Section of Dumb Drift and Ventilating Furnace.

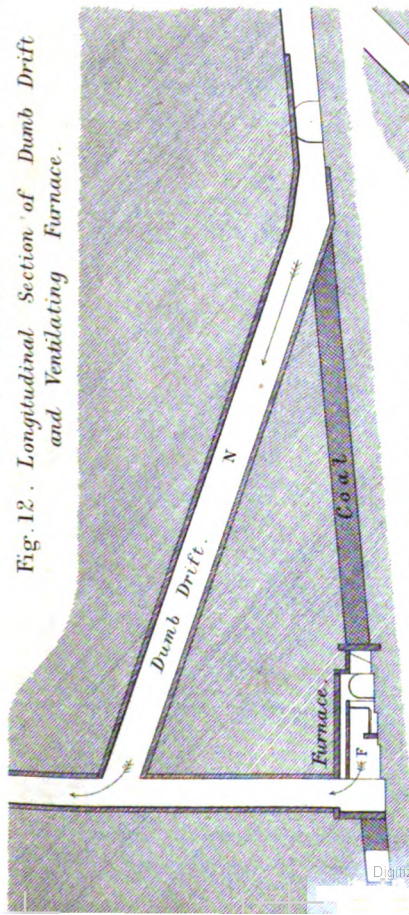


Fig. 13. Plan of Dumb Drift.

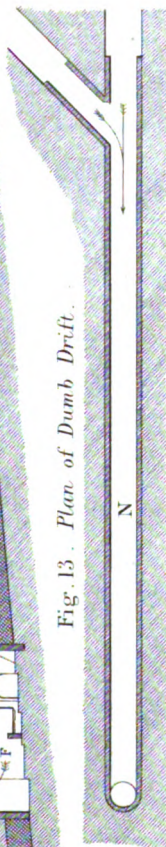


Fig. 14. Plan of Furnace.

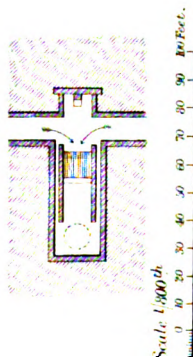


Fig. 15. Front Elevation of Ventilating Furnace.

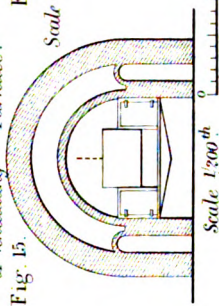


Fig. 16. Transverse Section of Dumb Drift.



Plate 29.
Wrought Iron
Punchcon.

Fig. 17.

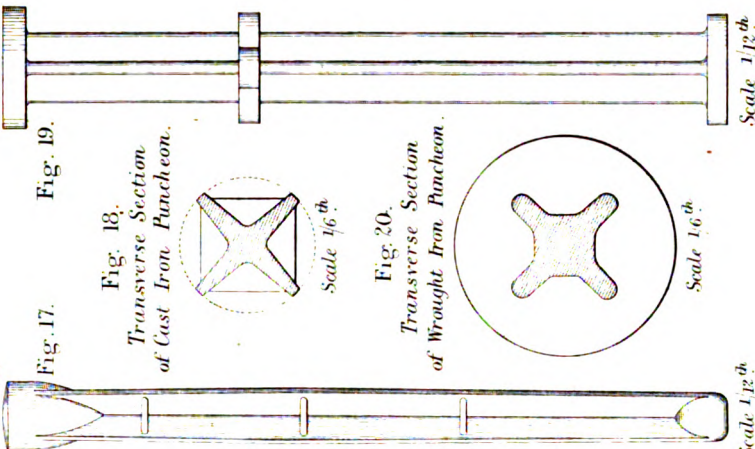


Fig. 18.
Transverse Section
of Cast Iron Punchcon.

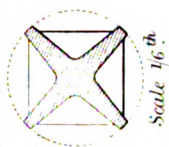
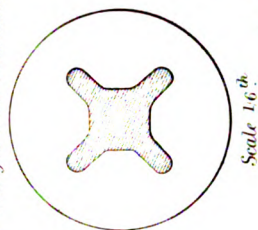


Fig. 20.

Transverse Section
of Wrought Iron Punchcon.



Scale 1/12th.

Scale 1/12th.

FEED - PIPE CONNEXION.

Plate 30.

Fig. 1.

Elevation of Connecting Tube between engine and tender.

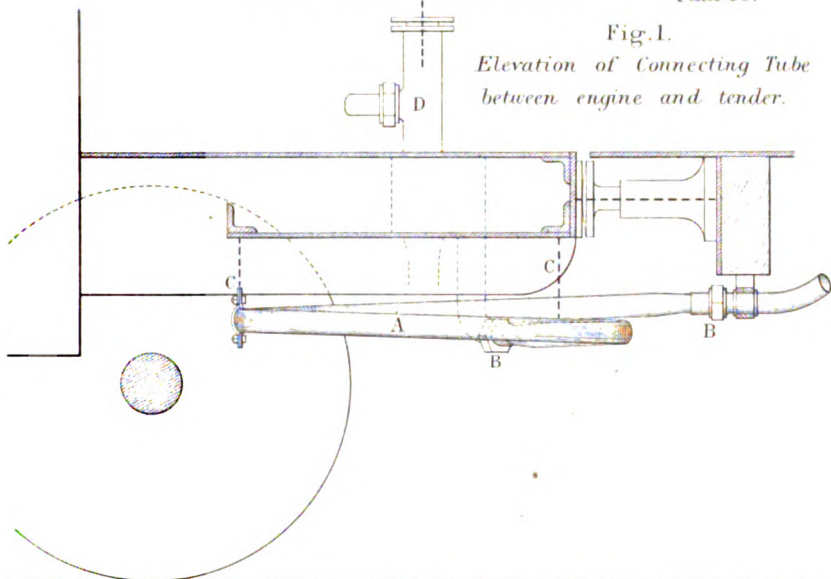


Fig. 2. Plan of Connecting Tube.

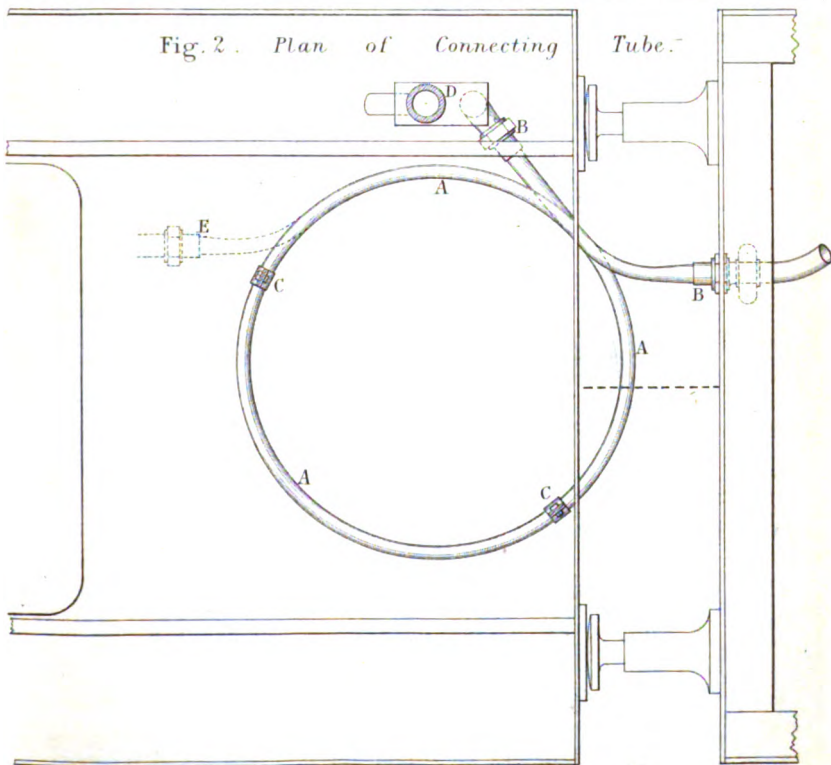


Fig. 3.
Sectional Plan of
End of Connecting Tube.

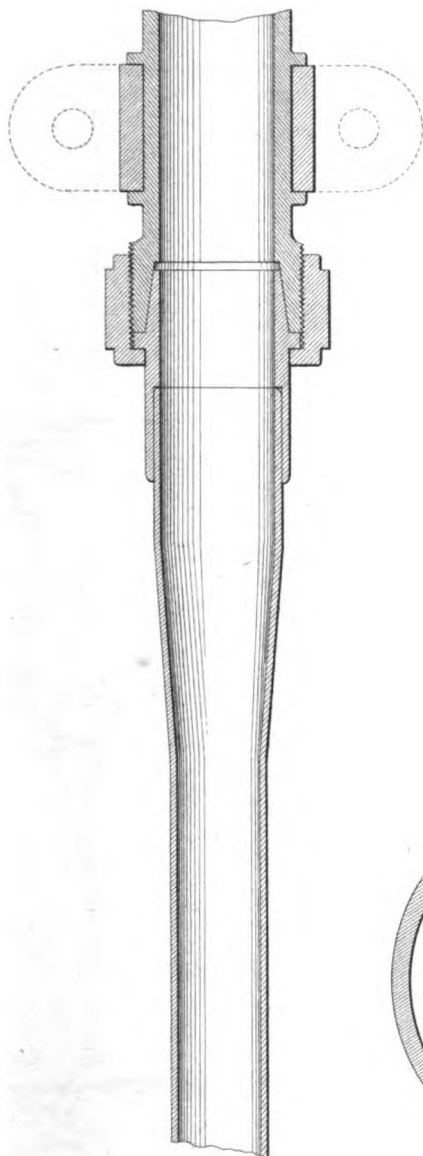
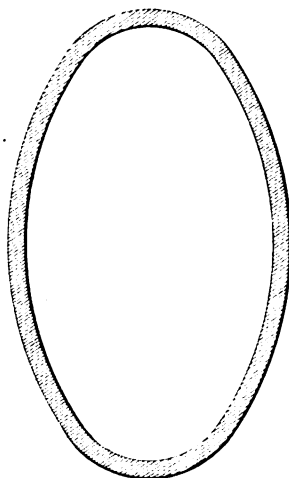
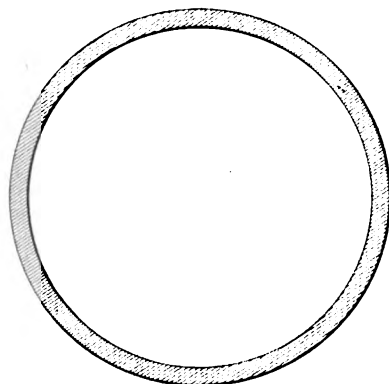


Fig. 4.
Section of
Elliptical Tube.



Full size.

Fig. 5.
Section of
Circular Tube.

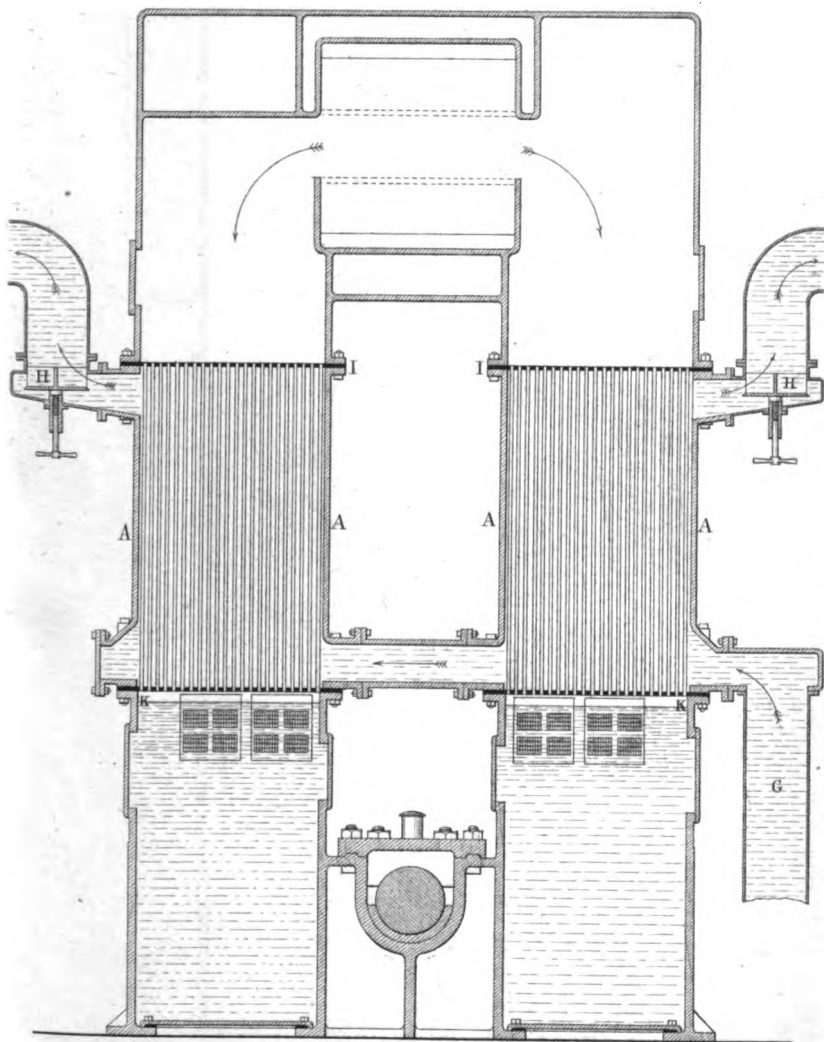


Full size.

Scale $\frac{1}{3}^{\text{rd}}$ full size.

(Proceedings Inst. M.E. 1862. Page 88.)

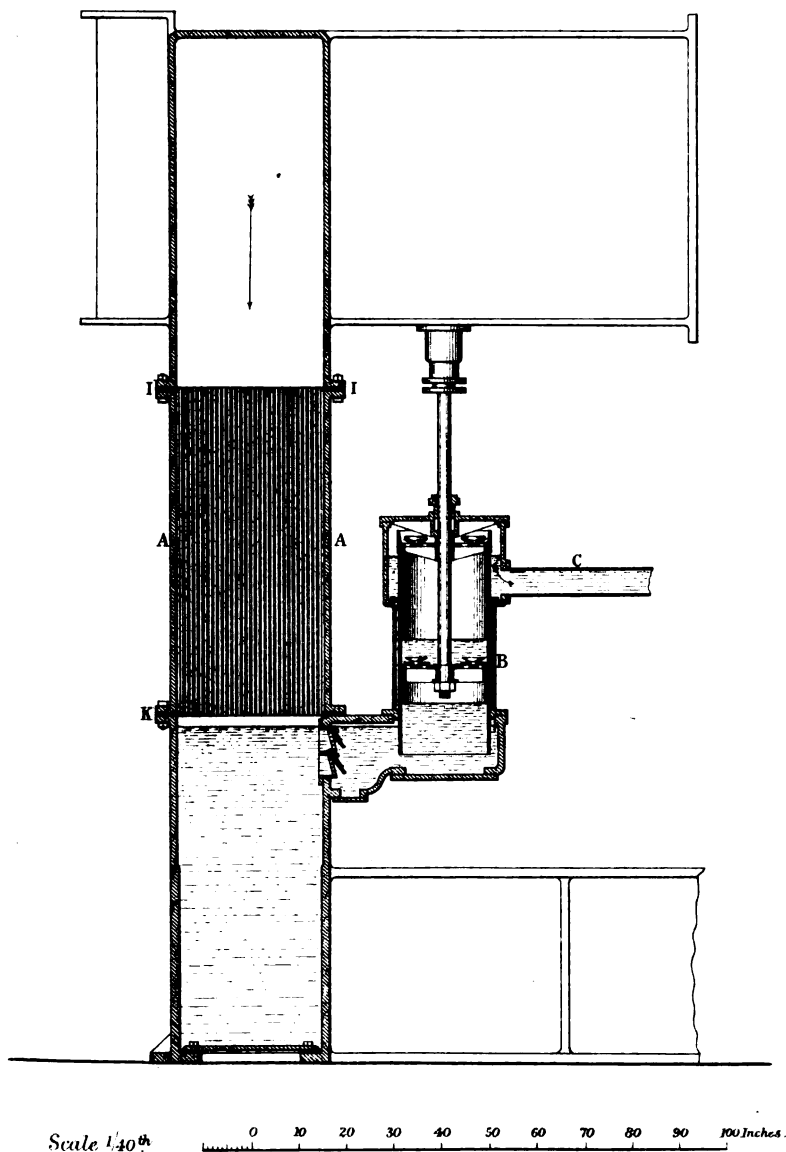
Fig.1. *Thwartship Section*
through Condensers.



Scale 1/40th

0 10 20 30 40 50 60 70 80 90 100 Inches

Fig. 2. Fore and Aft Section
through Condenser and Airpump.



SURFACE CONDENSER.

Fig. 3. Detail of firing of Tubes.

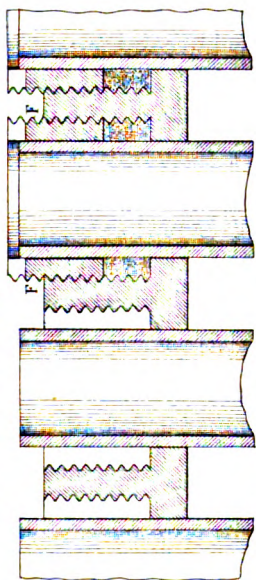


Fig. 5. Screwed Gland.

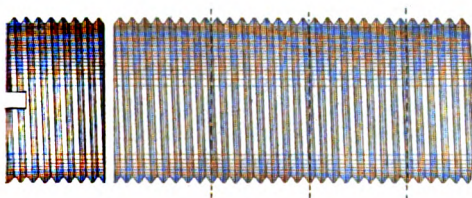


Fig. 7. Drill.

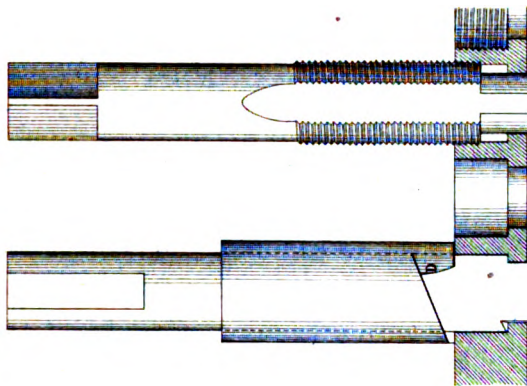


Fig. 9. Tap.

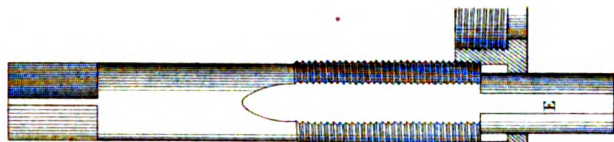


Fig. 12. Plan.



Fig. 8. Plan. Fig. 10. Plan.



Full size.

Half full size.

Fig. 4. Plan.

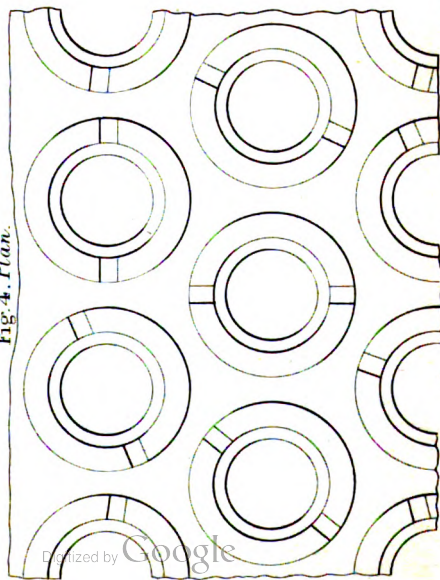
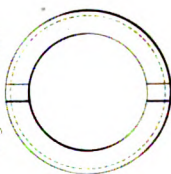


Fig. 6. Plan.



Indicator Diagrams from engines of "Mooltan." 1861.

Vacuum in condensers 28 inches of mercury.

Pressure of steam in boilers 17 lbs. 58 Revolutions per minute.

Fig. 13. Indicator Diagram from Top of cylinder.

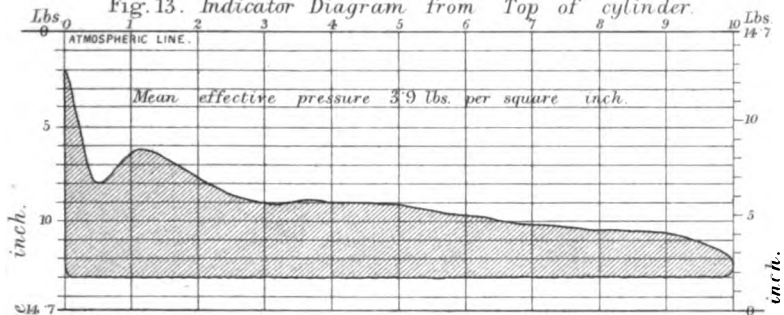


Fig. 14. Indicator Diagram from Bottom of cylinder.

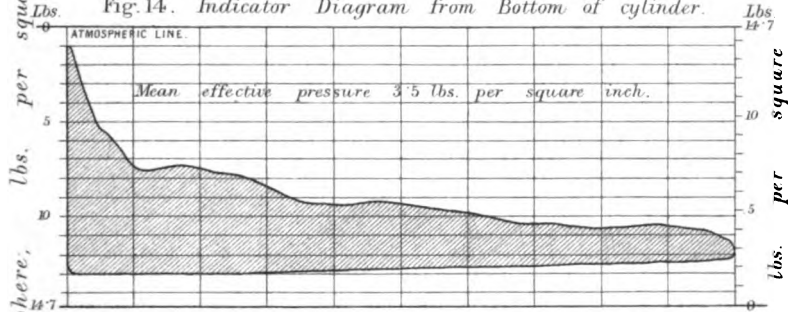


Fig. 15. Indicator Diagram from engines of "Wilberforce." 1838.

Vacuum in condensers 28 inches of mercury.

Pressure of steam in boilers 6 lbs. 19 Revolutions per minute.

Cylinders 60 inches diam., 6 feet stroke.

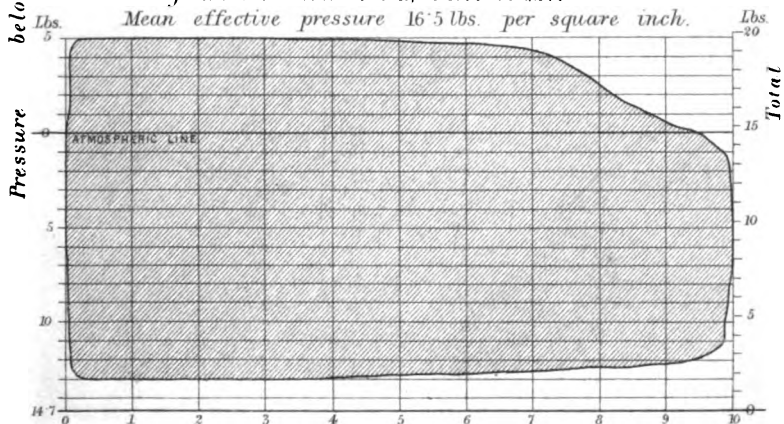


Fig. 1. Side Elevation of Rifling Machine.

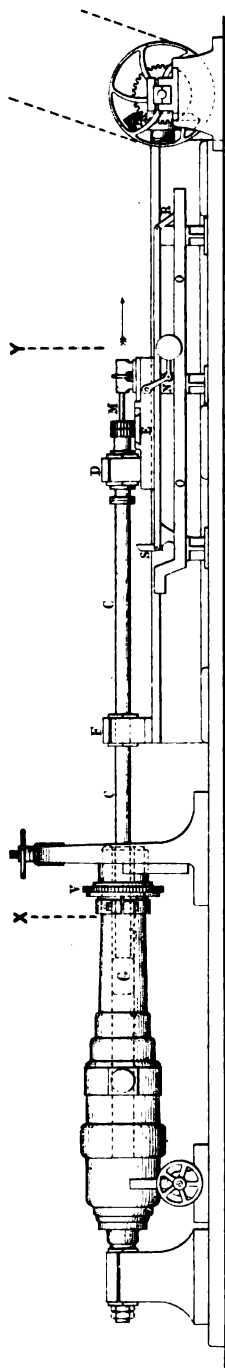
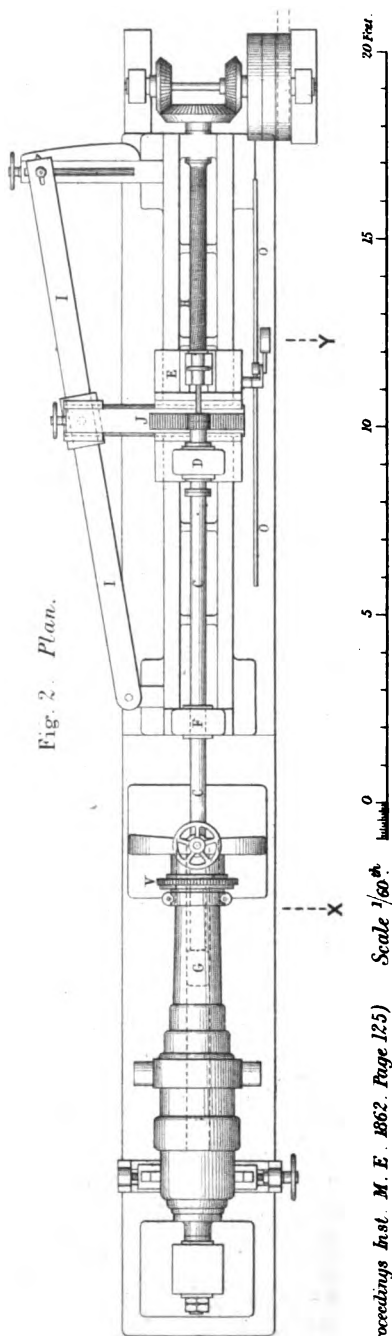


Fig. 2. Plan.



(Proceedings Inst. M. E. 1862. Page 125)

Scale $\frac{1}{60}$ in.

0

5

10

15

20 Feet.

Fig. 3.
Transverse Section at XX.

Fig. 5. Side Elevation of Traversing Saddle carrying Rifling Bar.

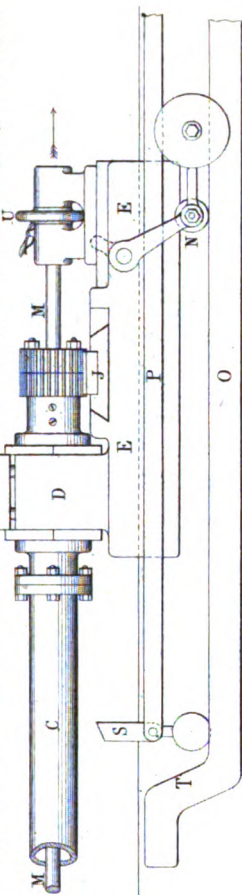


Fig. 4. Transverse Section at YY.

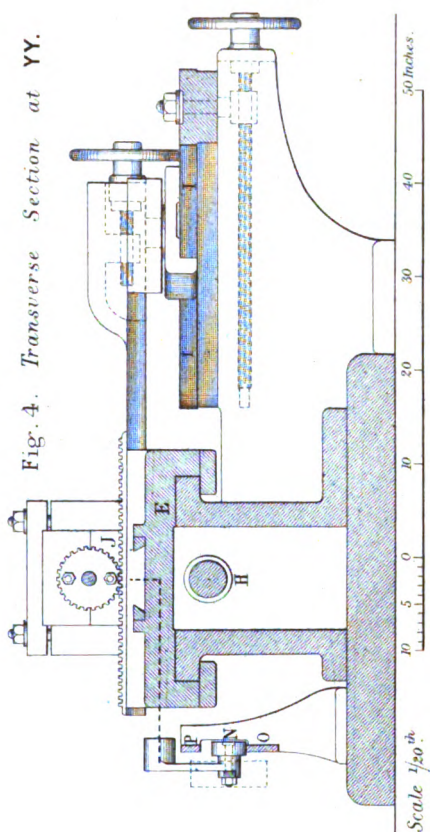


Fig. 6. Diagram of principal motions of Rifling Machine.

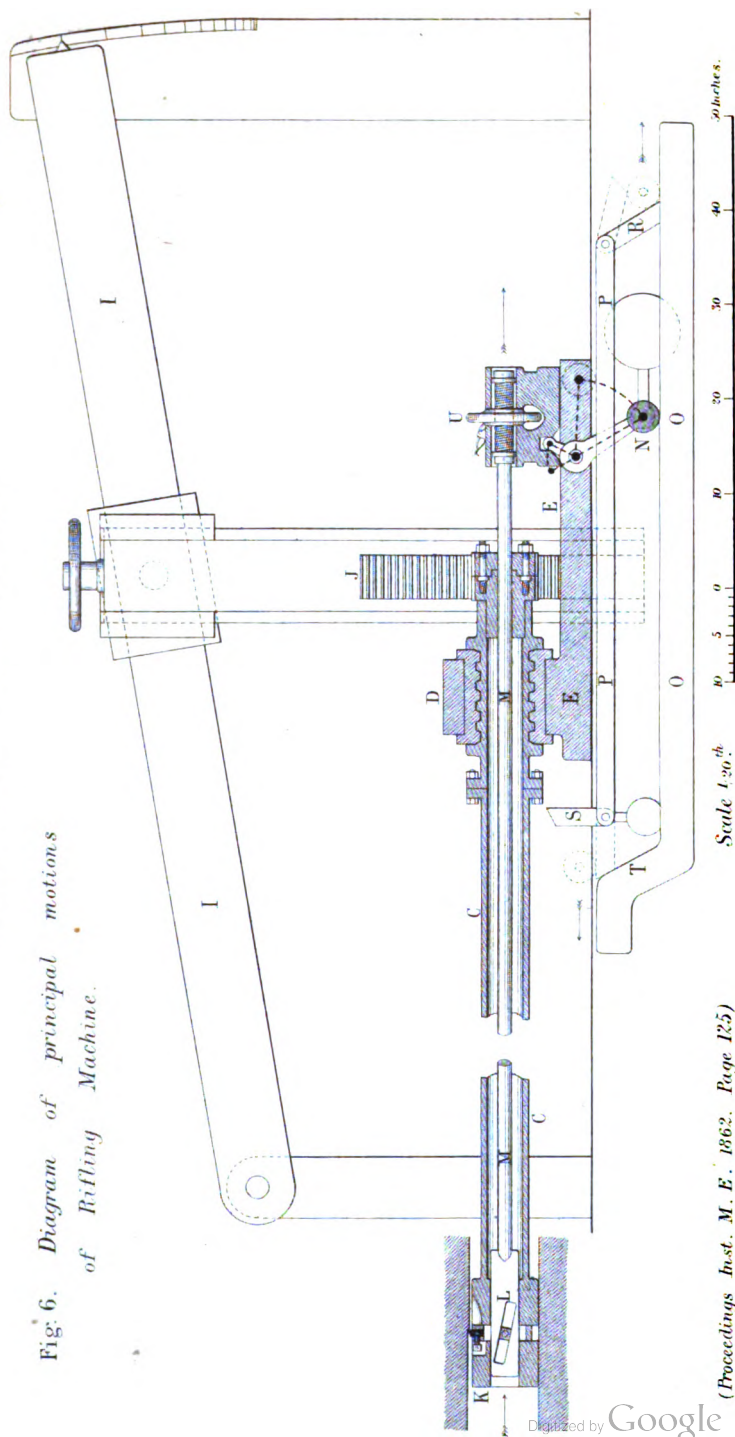


Fig. 7. *Broaching Bar for final boring of gun.* Scale $\frac{1}{16}$ th.

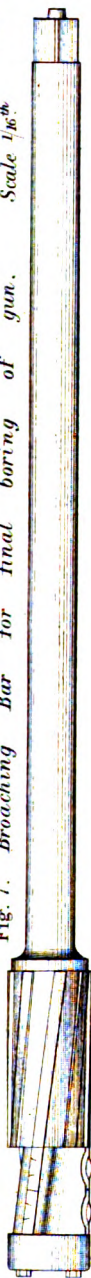


Fig. 8. *Twisted Rifling Bar.* Scale $\frac{1}{16}$ th.



Fig. 11. *Rifling Head with fixed cutters.*

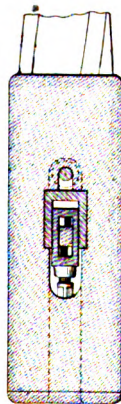


Fig. 10. *Head of Broaching Bar for final boring.*

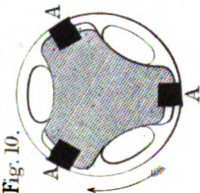


Fig. 9.

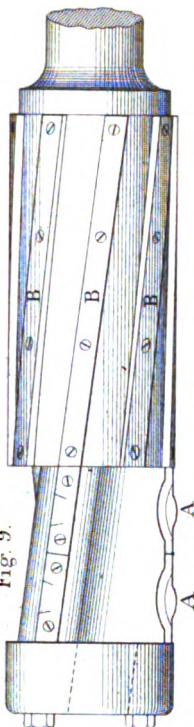


Fig. 12. *Rifling Head with fixed cutters.*

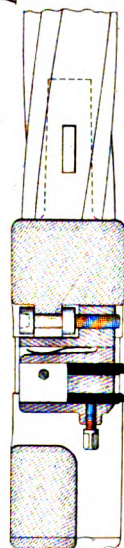


Fig. 13. *Section of Twisted Rifling Bar.*



Fig. 14. *Rifling Head with feed motion for cutter.*

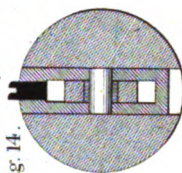
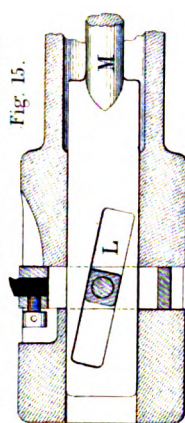


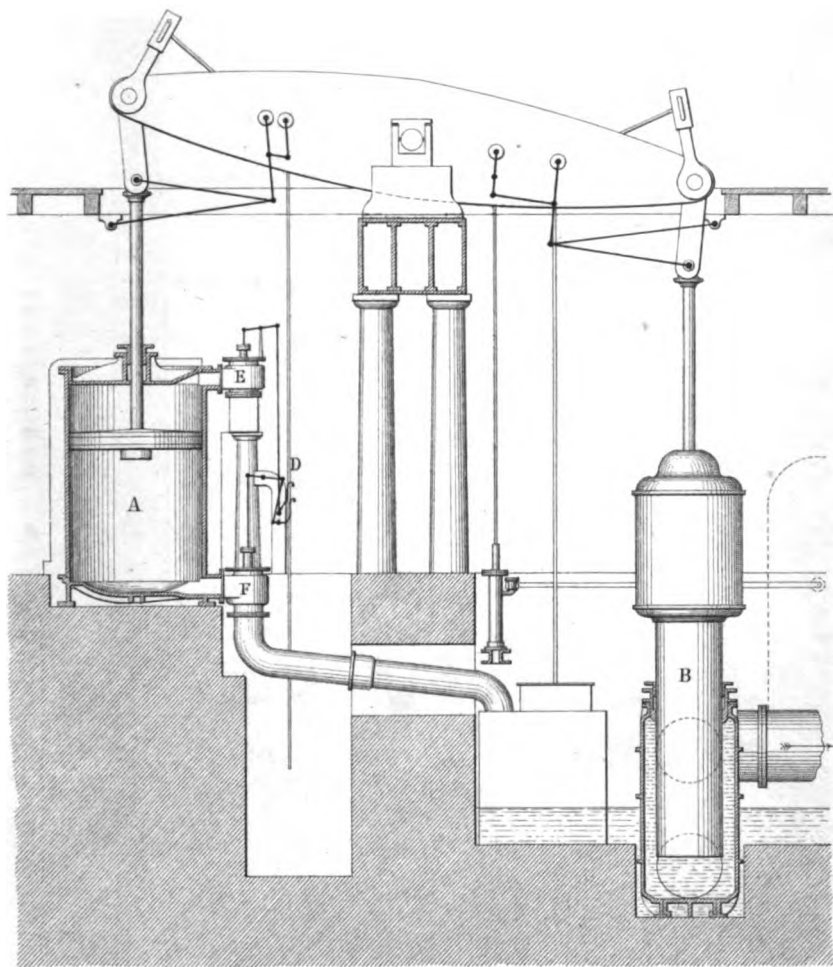
Fig. 15.



Scale $\frac{1}{8}$ th.

30 inches.

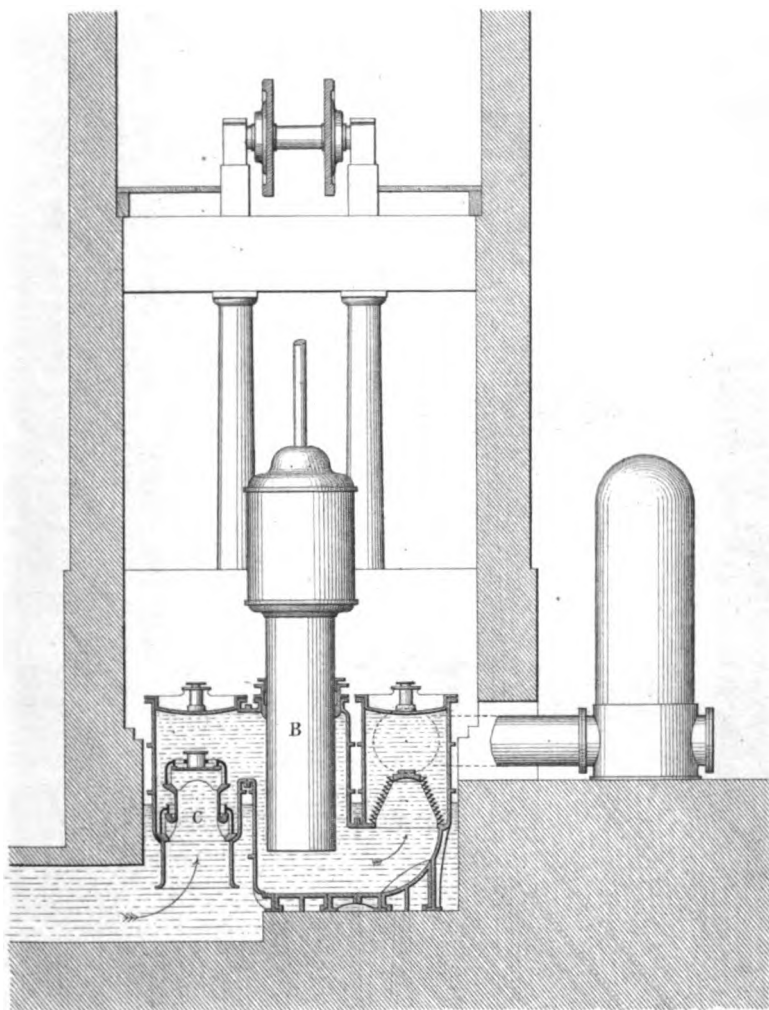
Fig.1. *Longitudinal Section of Engine at East London Water Works.*



Scale $\frac{1}{140}^{\text{th}}$

10 5 0 10 20 30 Feet.

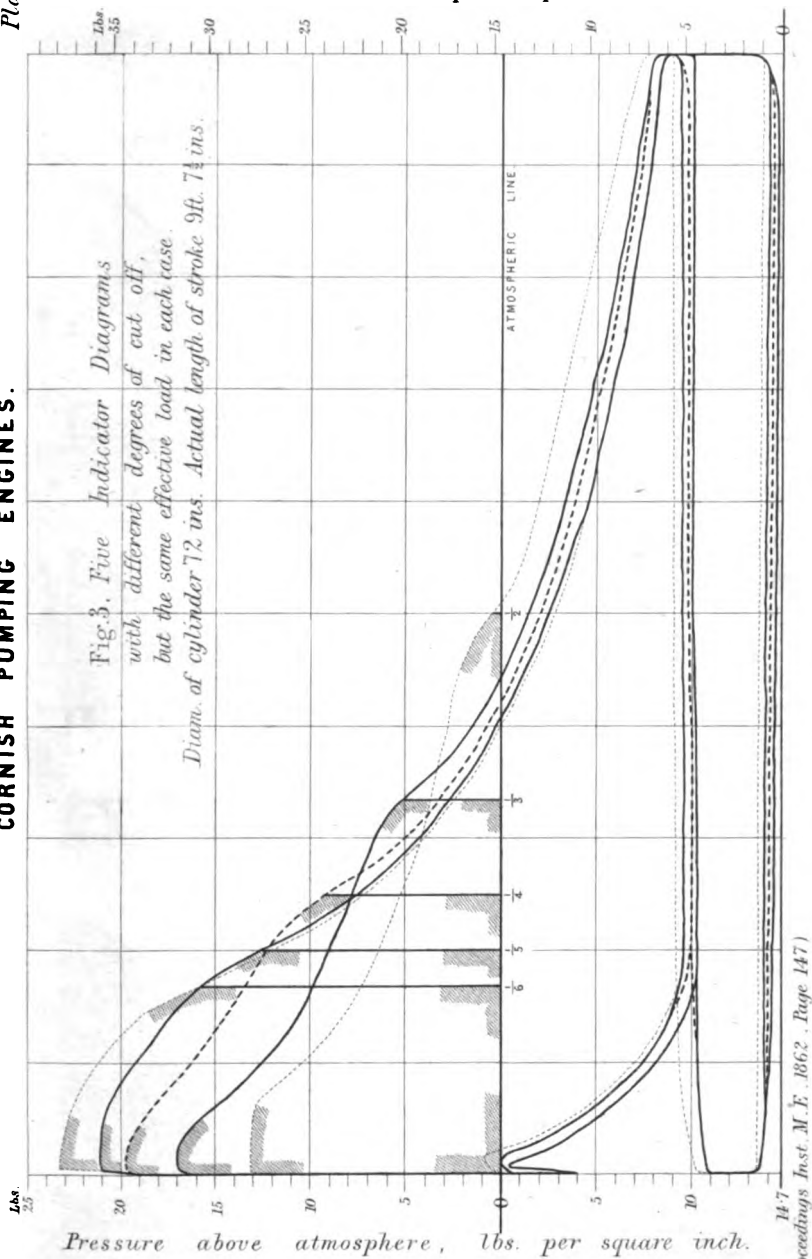
Fig. 2. *Transverse Section of Engine
at East London Water Works.*



Scale $\frac{1}{140}^{th}$.

10 5 0 10 20 30 Feet.

Total Pressure, lbs. per square inch.



(Proceedings Inst. M.E. 1862, Page 147)

Indicator Diagrams from 72 inch cylinder.

Total Load equal to 15 lbs. per square inch on the piston.

Actual length of stroke 9ft 7½ ins.

Fig. 4. *Steam cut off at $\frac{1}{2}$ stroke.*

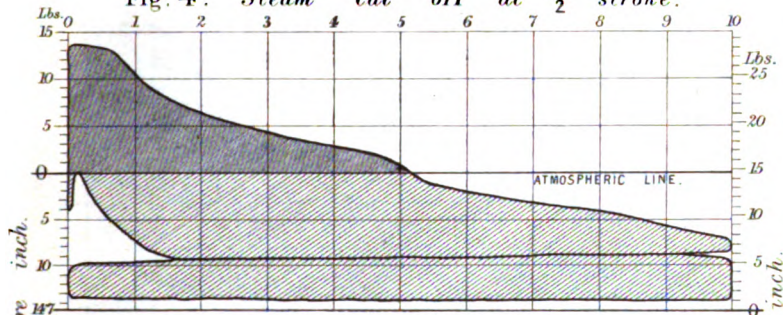


Fig. 5. *Steam cut off at $\frac{1}{3}$ stroke.*

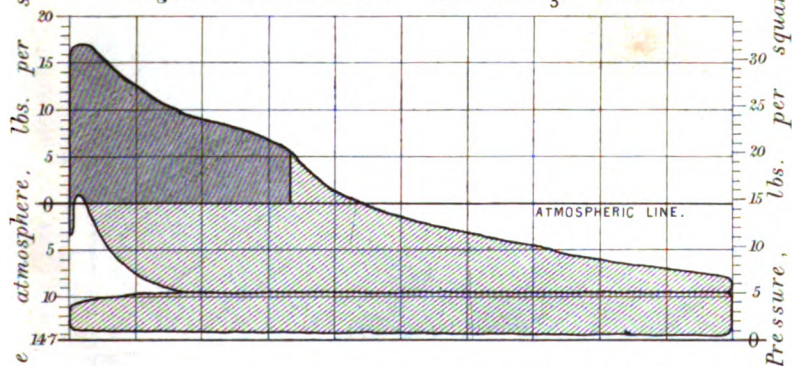
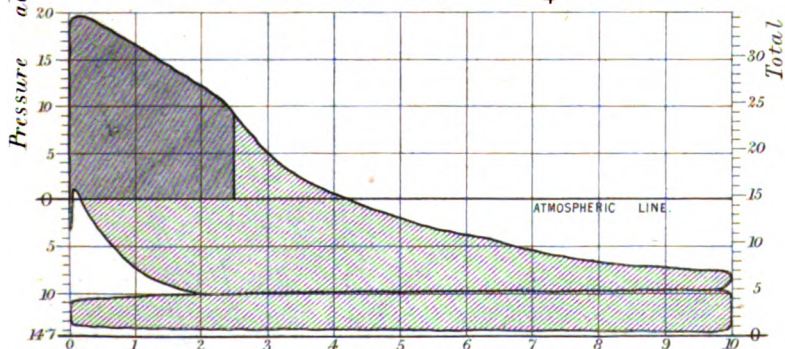


Fig. 6. *Steam cut off at $\frac{1}{4}$ stroke.*



(*Proceedings Inst. M.E. 1862. Page 147*)

*Indicator Diagrams from 72 inch cylinder
Total Load equal to 15 lbs. per square inch on the piston.
Actual length of stroke 9 ft. 7½ ins.*

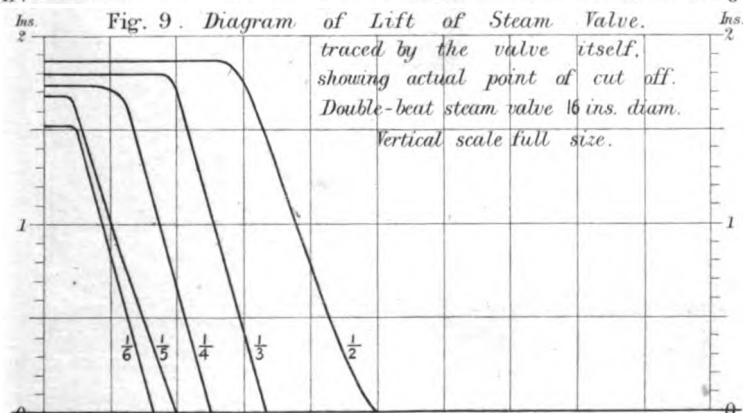
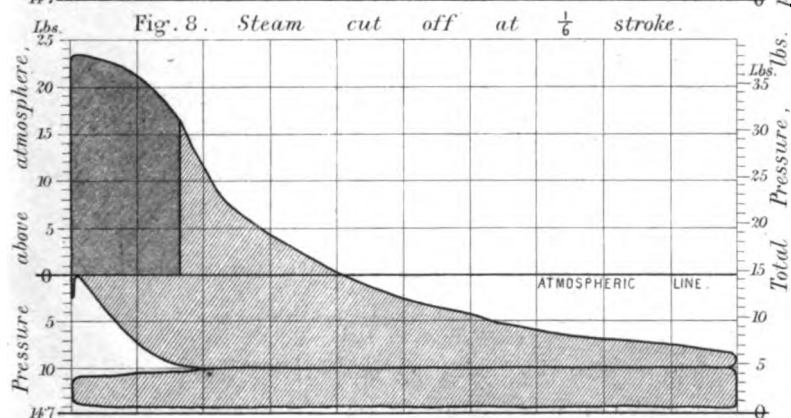
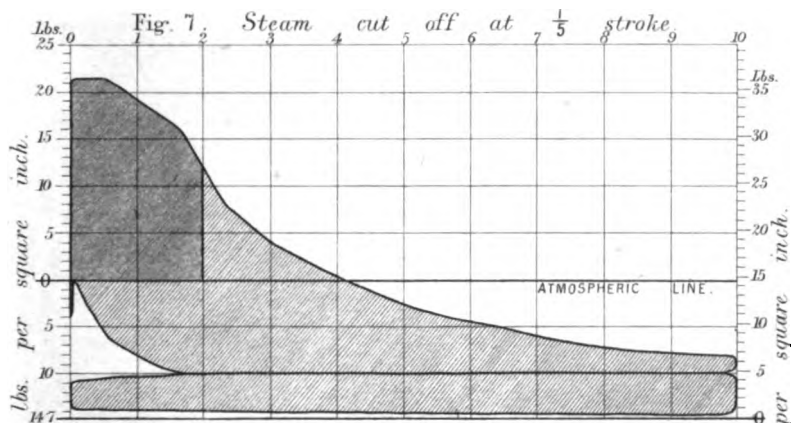


Fig. 10. Indicator Diagram from 80 inch cylinder.

Total Load equal to 14.38 lbs. per square inch on the piston.
Steam cut off at $\frac{1}{3}$ stroke. Actual length of stroke 9 ft. 9 ins.

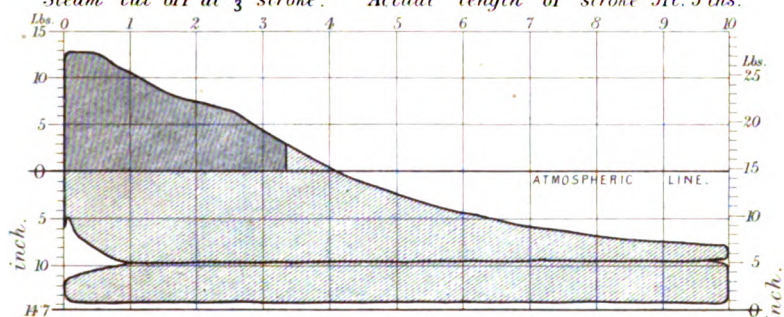


Fig. 11. Indicator Diagram from 90 inch cylinder.

Total Load equal to 15.58 lbs. per square inch on the piston.
Steam cut off at $\frac{1}{4}$ stroke. Actual length of stroke 10 ft. 7 ins.

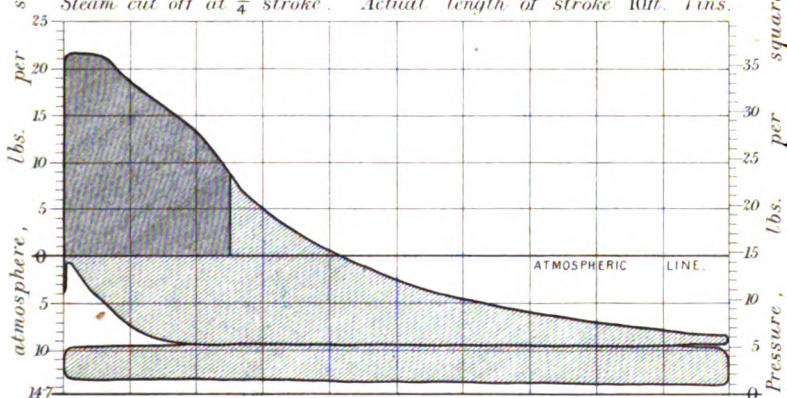


Fig. 12. Indicator Diagram from 100 inch cylinder.

Total Load equal to 16.58 lbs. per square inch on the piston.
Steam cut off at $\frac{1}{4}$ stroke. Actual length of stroke 11 ft.

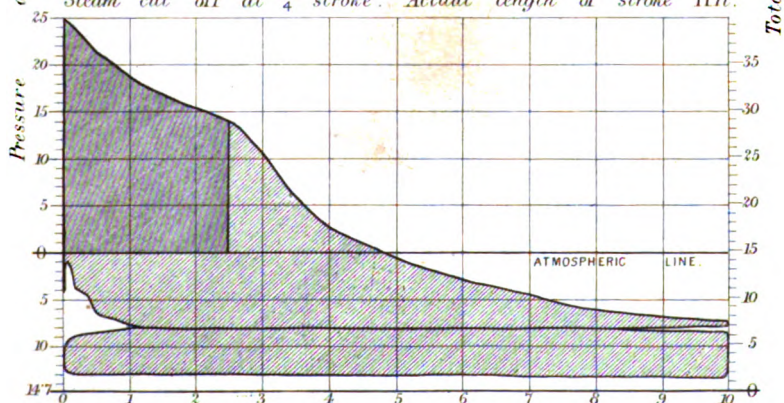


Fig. 1. Front Elevation.

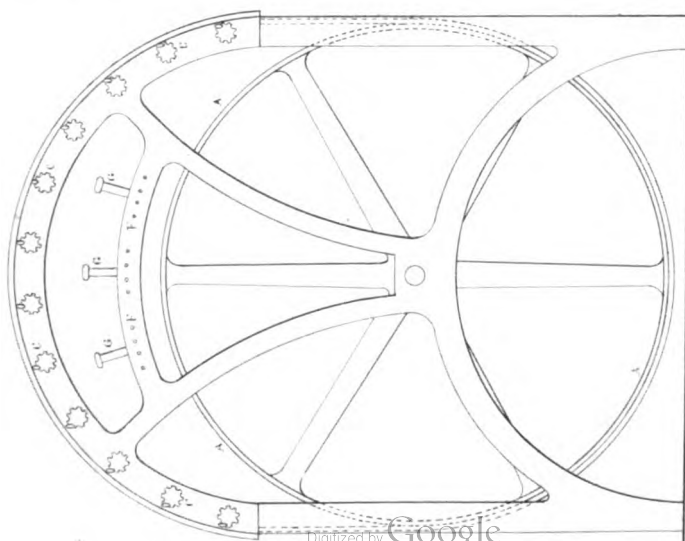


Fig. 2. Side Elevation.

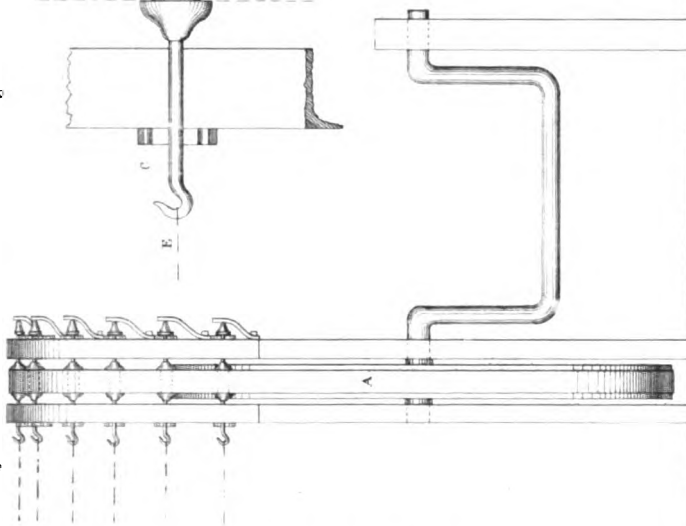


Fig. 3. Hook and Driving Roller enlarged.

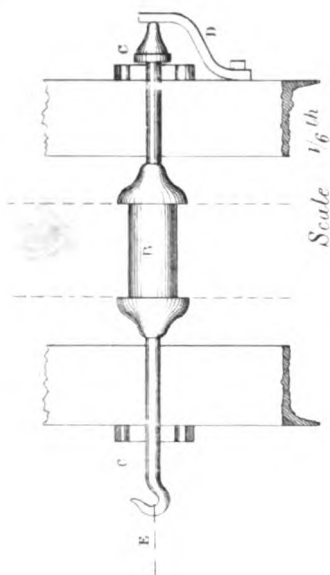


Fig. 4. Brass Bearing.



Scale $\frac{1}{16}$ th.

ROPE MANUFACTURE.

Fig. 5. Half Front Elevation.

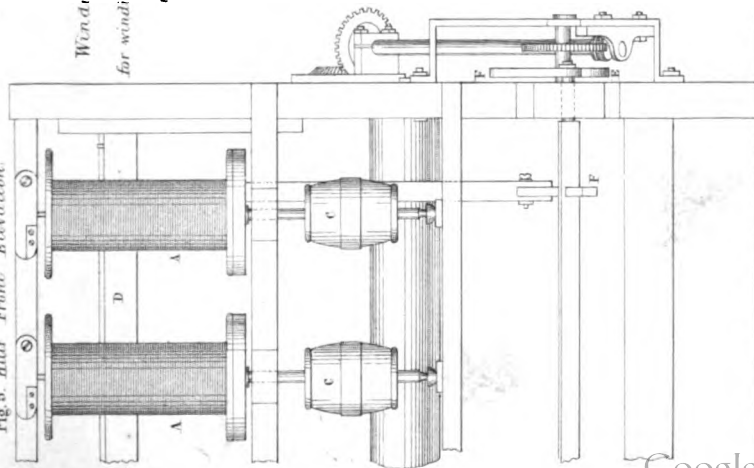
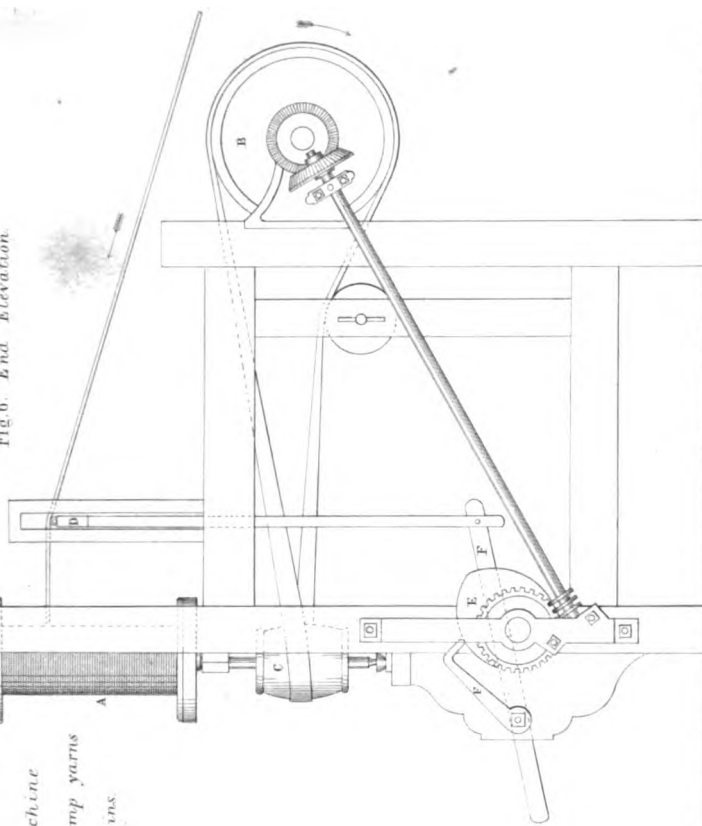


Fig. 6. End Elevation.

*Winding Machine
for winding the hemp yarns
upon bobbins.*

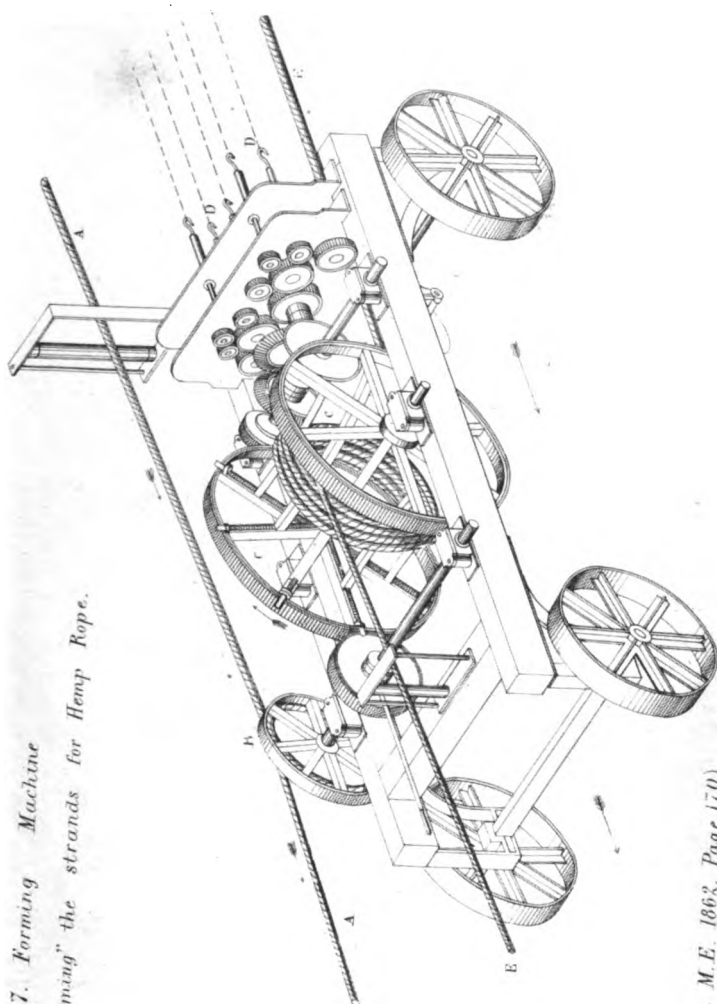


30 20 10 0 10 20 30 40 50 Inches

ROPE MANUFACTURE.

Plate 18.

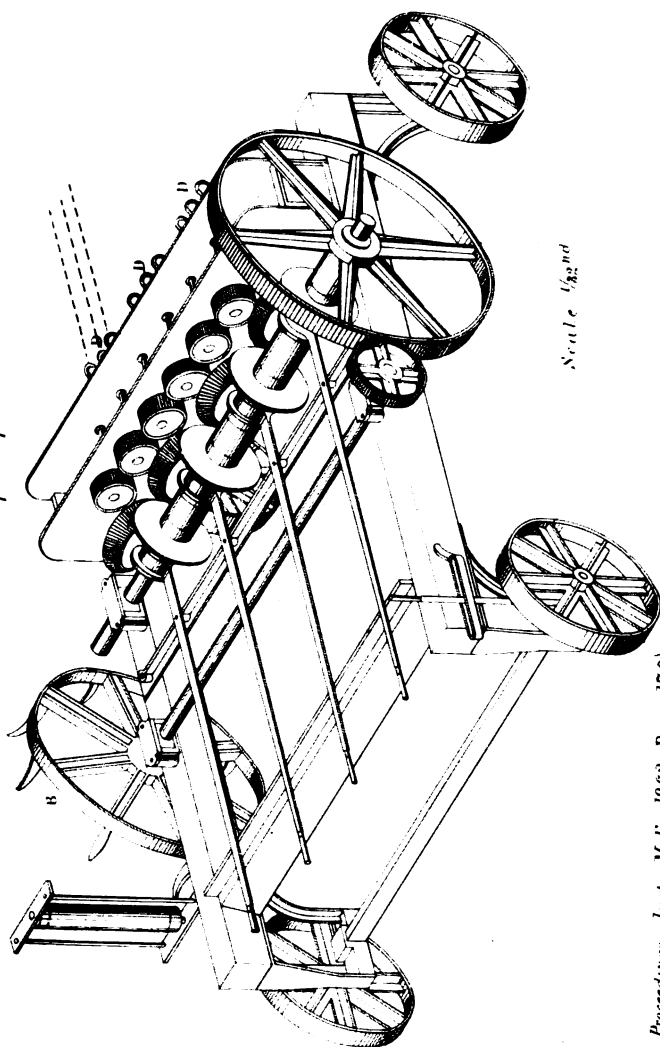
Fig 7. Forming Machine
for "forming" the strands for Hemp Rope.



(Proceedings Inst. M.E., 1862, Page 170)

Scale 1/32nd

Fig. 8. Upper End Laying Machine
for "Laying" the strands of Hemp Rope



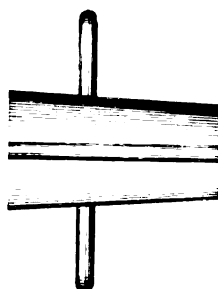
Scale 1/32nd

Laying Top.

Fig. 9. End View.

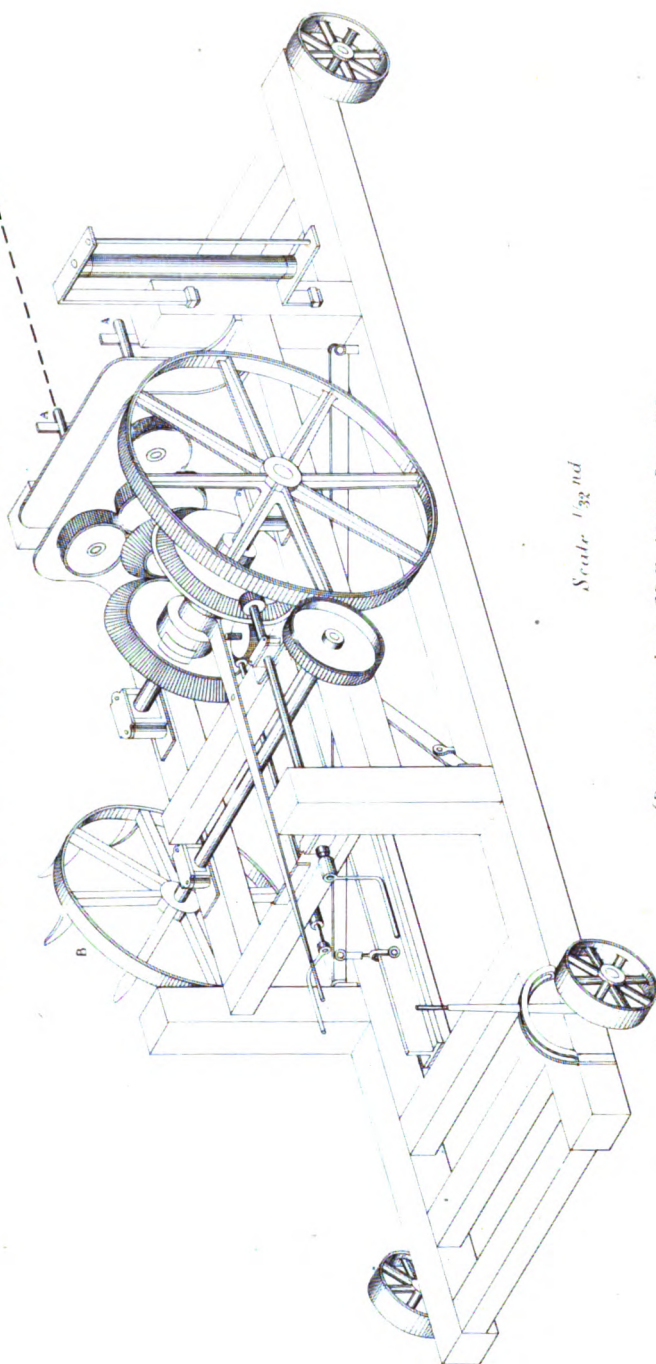


Fig. 10. Plan.



Scale 1/16th

Fig. 11. Lower End Laying Machine for "laying" the strands of Hemp Rope.



Scale 1/32nd

(Proceedings Inst. M. E. 1862 Page 170)

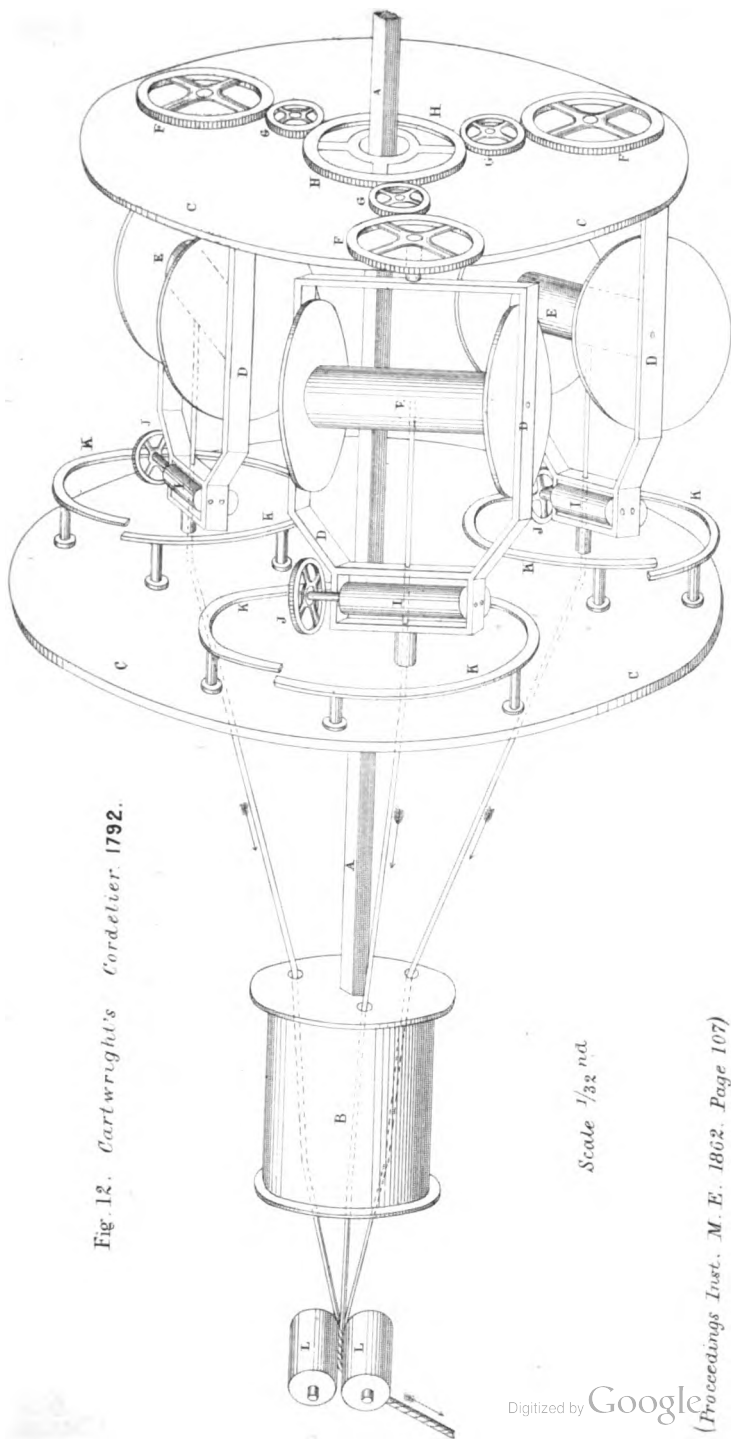
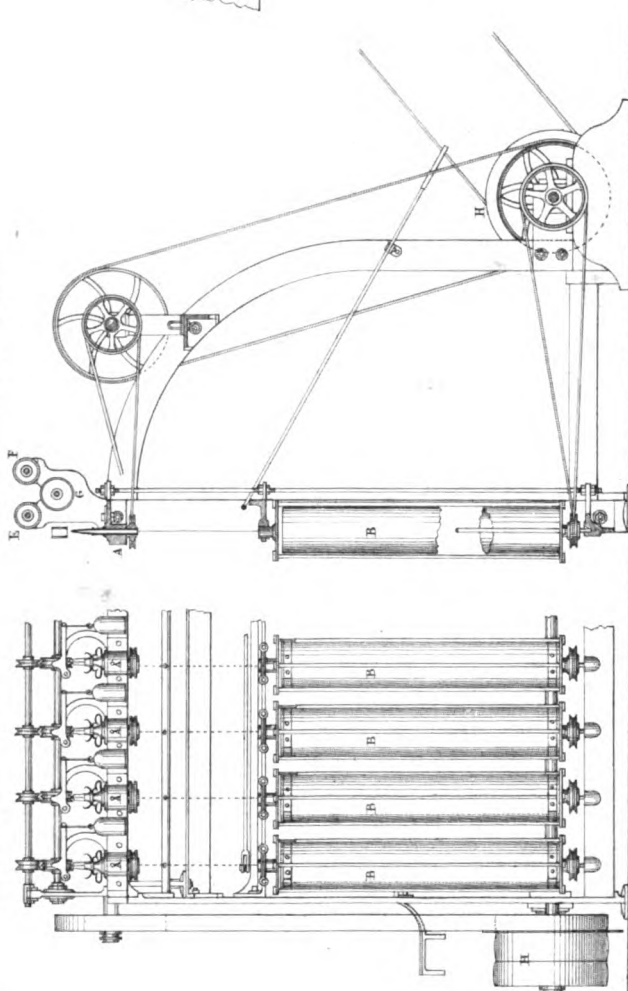


Fig. 12. Cartwright's Cordelier. 1792.

Scale $\frac{1}{32}$ in.

ROPE MANUFACTURE.
Spinning Machine for spinning hemp sliver into yarn.

Fig 13. Front Elevation.



Scale $\frac{1}{4}$ th Ins. 12
(Proceedings Inst. M.E. 1862, Page 170)

Fig 14. Transverse Section.

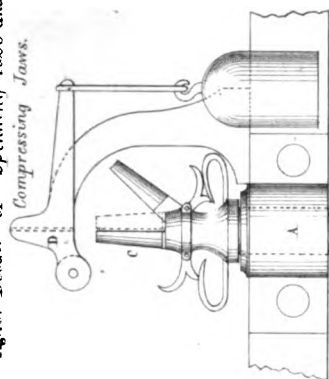
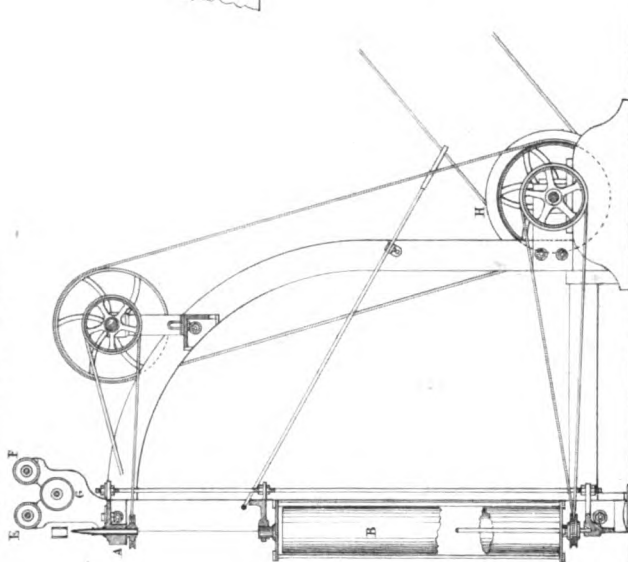


Fig 16. Plan of Clap.



Fig 17. Plan of Compressing Jaws.

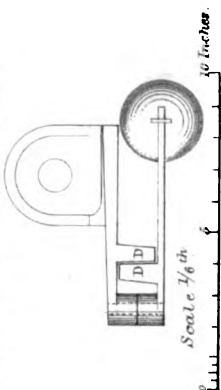
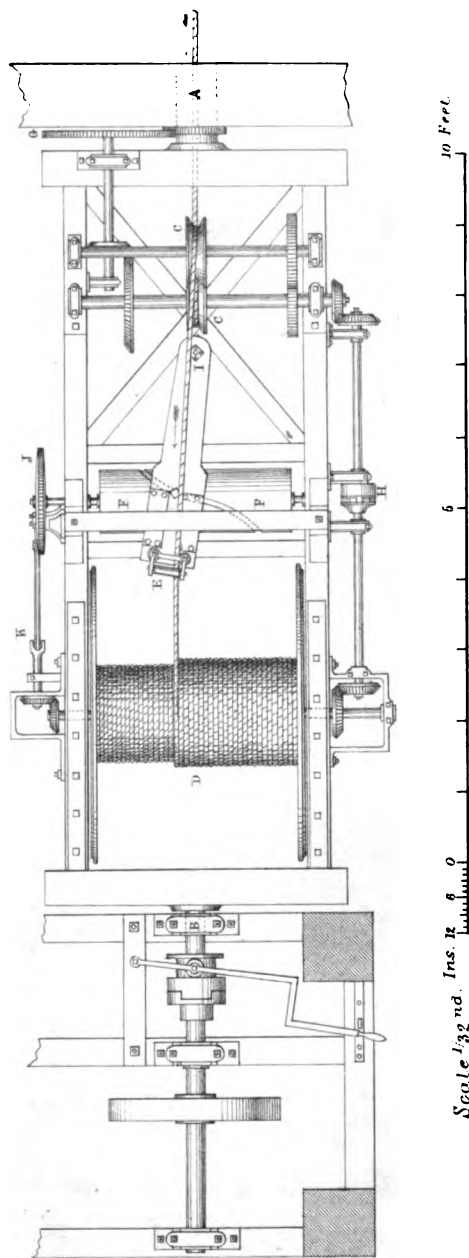


Fig. 18. Plan of "Registering" Machine

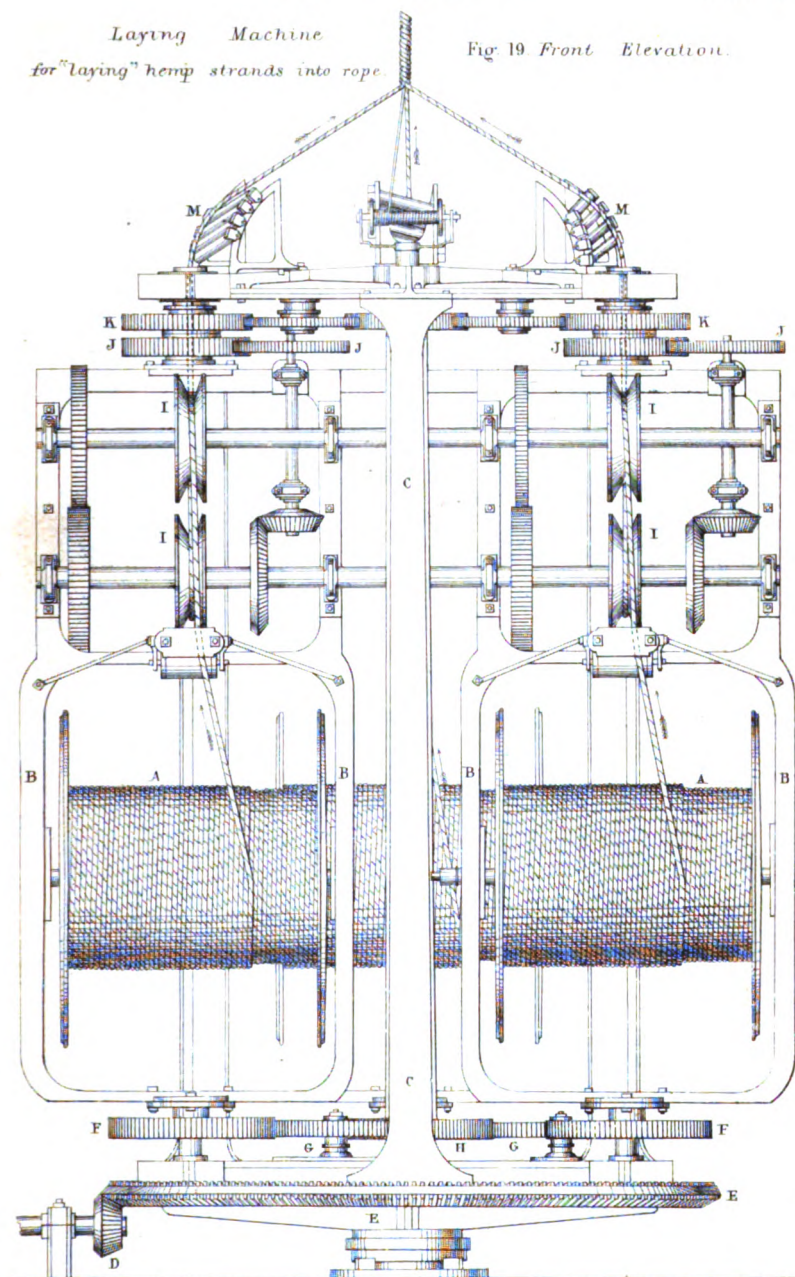
for twisting hemp yarns into a strand and winding the strand on a drum.



Scale $1/32^{\text{nd}}$. Ins. R. 8 0

Laying Machine
for "laying" hemp strands into rope.

Fig. 19. Front Elevation.



Scale $\frac{1}{36}^{th}$

0 1 2 3 4 5 6 7 8 9 10 11 12 Feet

Laying Machine for "laying" hemp strands into rope.

Fig 20.

Plan at top

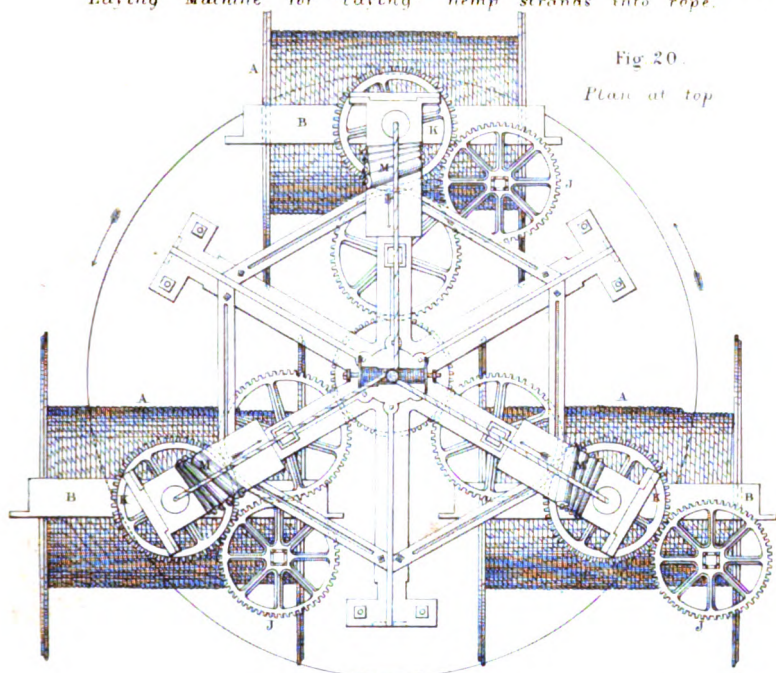
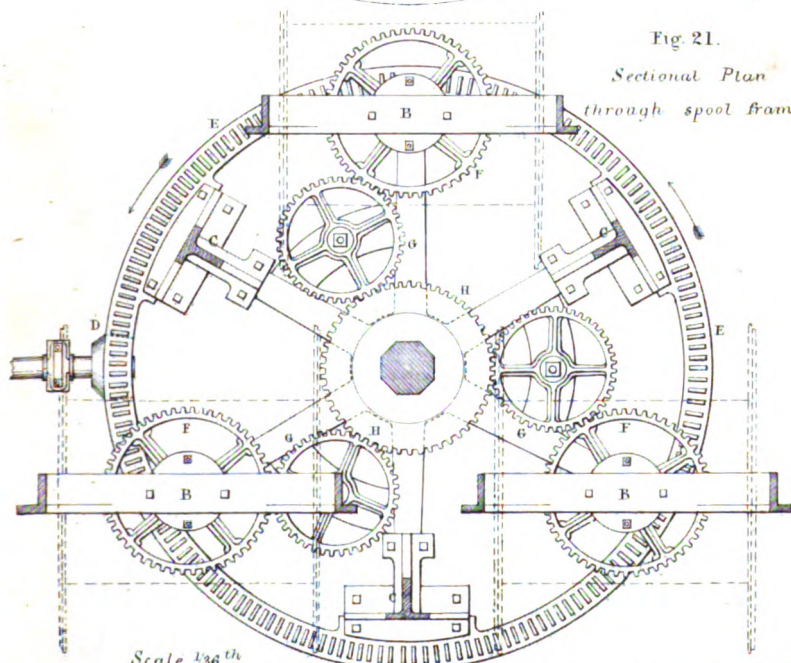


Fig. 21.

Sectional Plan
through spool frames.



Scale $\frac{1}{36}$ th

0 1 2 3 4 5 6 7 8 9 10 11 12 Feet

(Proceedings Inst. M E. 1862. Page 170)

Digitized by Google

Laying Machine
for "laying" hemp strands into rope.

Fig 22.
Side Elevation
of Spool Frame
enlarged

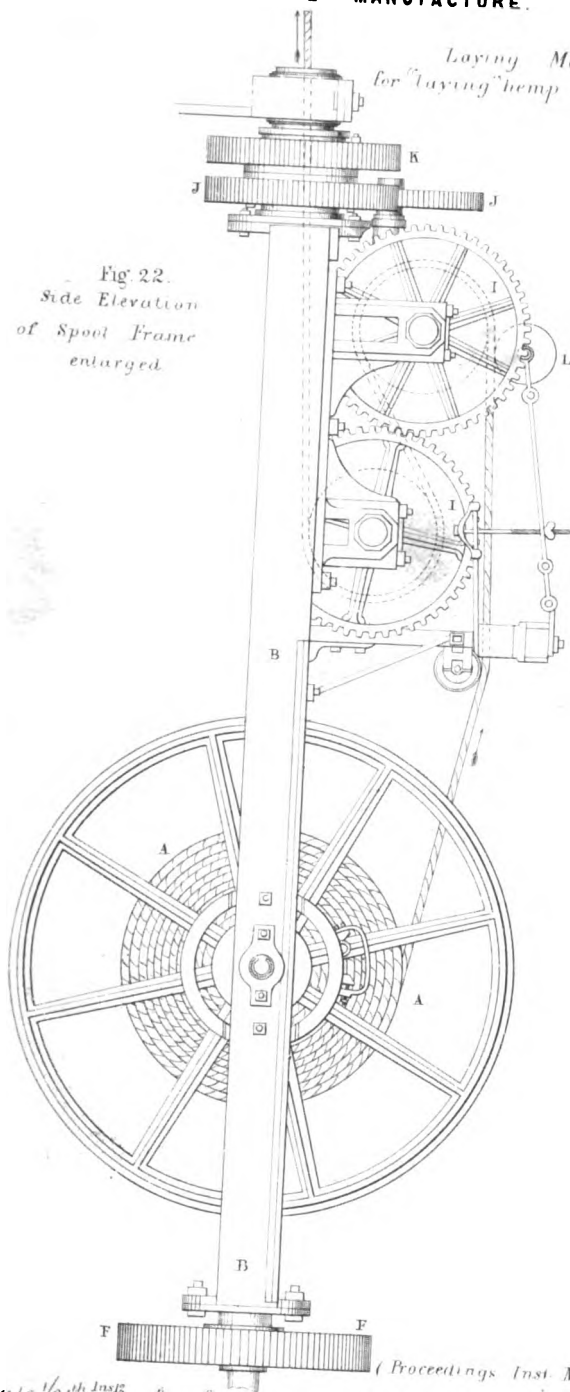
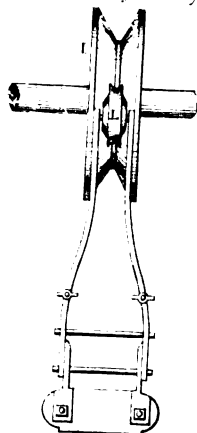


Fig 23.
Tightening Pulley



Wire Ropes.

Fig. 24. *Freiburg Suspension Bridge Cable.* 1835.
Scale $\frac{1}{24}^{\text{th}}$

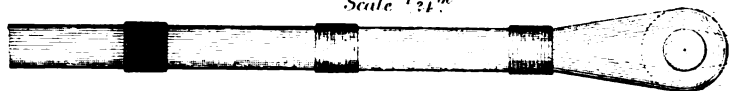


Fig. 25. "Selvage" Wire Rope. 1835.



Fig. 26.



Fig. 27. "Formed" Wire Rope. 1837.



Fig. 28.



Fig. 29. *First Flat Wire Rope.* 1836.

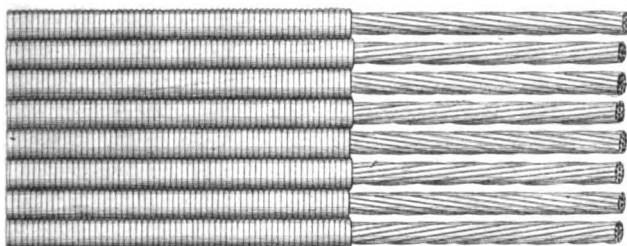


Fig. 30.



Fig. 31. *Second Flat Wire Rope.* 1837.

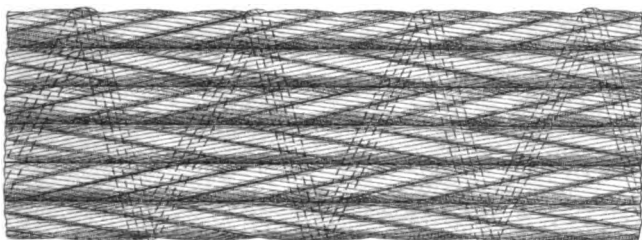


Fig. 32.



Fig. 33. "Laid" Wire Rope. 1838.



Fig. 34.



(Proceedings Inst. M.E. 1862. Page 170.)

Scale $\frac{1}{3}^{\text{rd}}$ full size.

ROPE MANUFACTURE.

Plate 58.

Fig. 35.

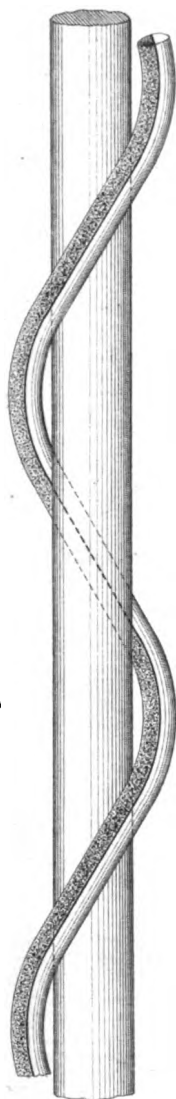


Fig. 36.

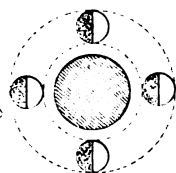


Fig. 37.

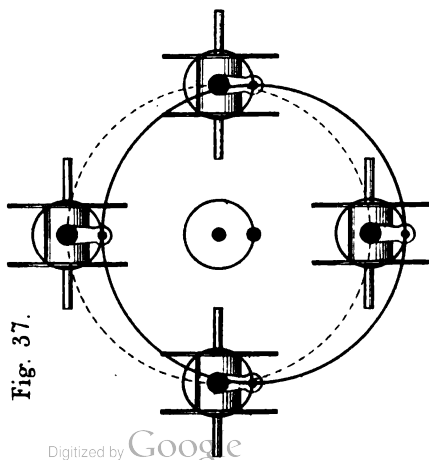


Fig. 38.

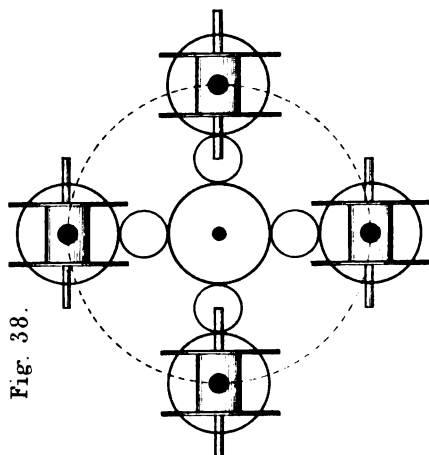
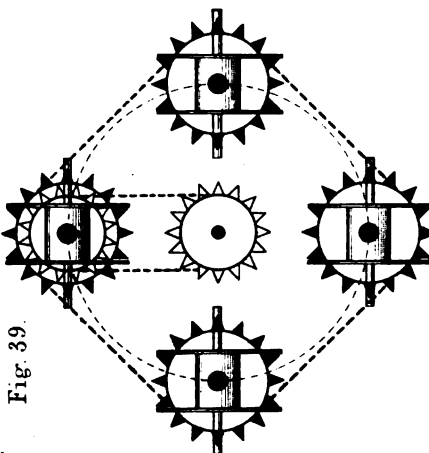


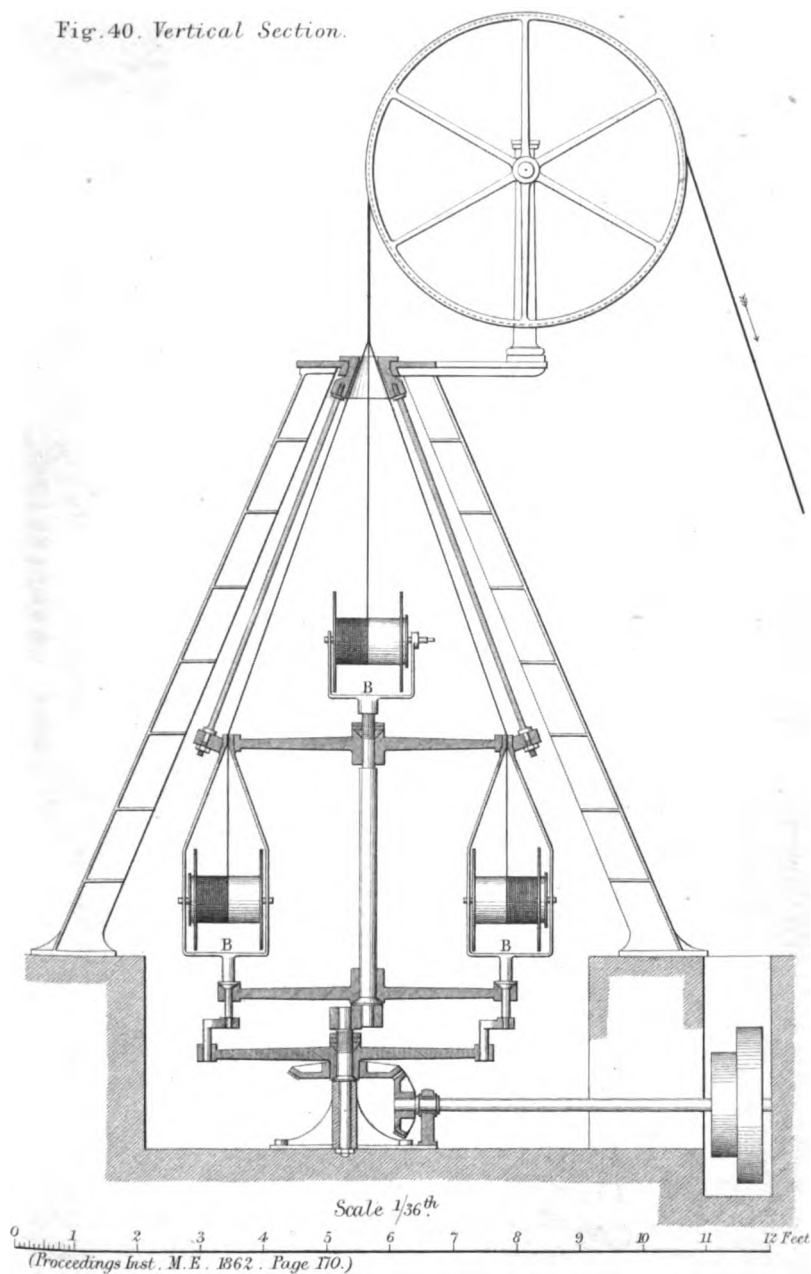
Fig. 39.



(Proceedings Inst. M. E. 1862. Page 170.)

Huddart's Wire Rope Machine.

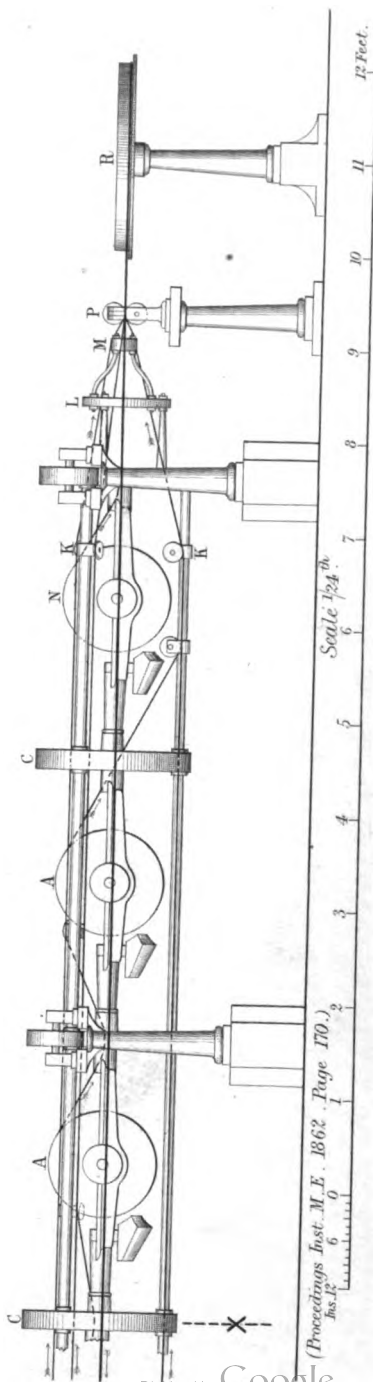
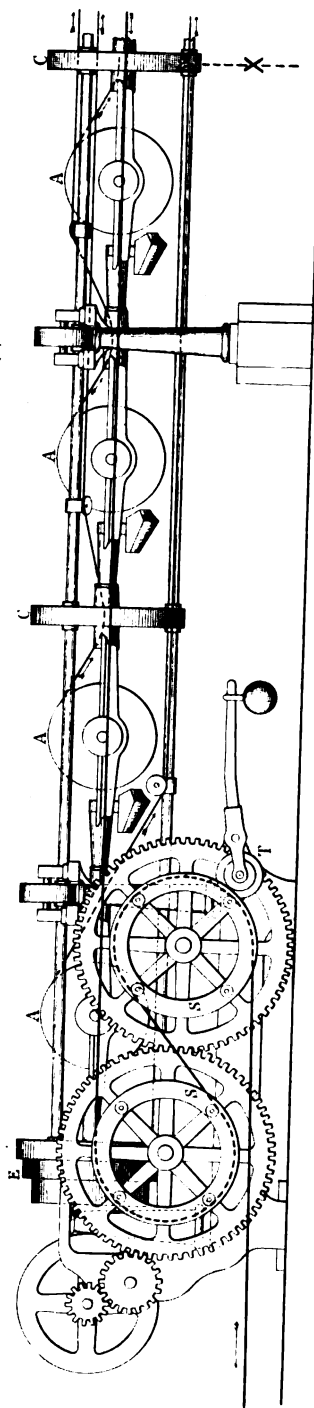
Fig. 40. Vertical Section.



ROPE MANUFACTURE.

Plate 60.

Smith's Wire Rope Machine. Fig. 41. Side Elevation.



(Proceedings Inst. M.E. 1862. Page 170.)

Scale 1/24th.

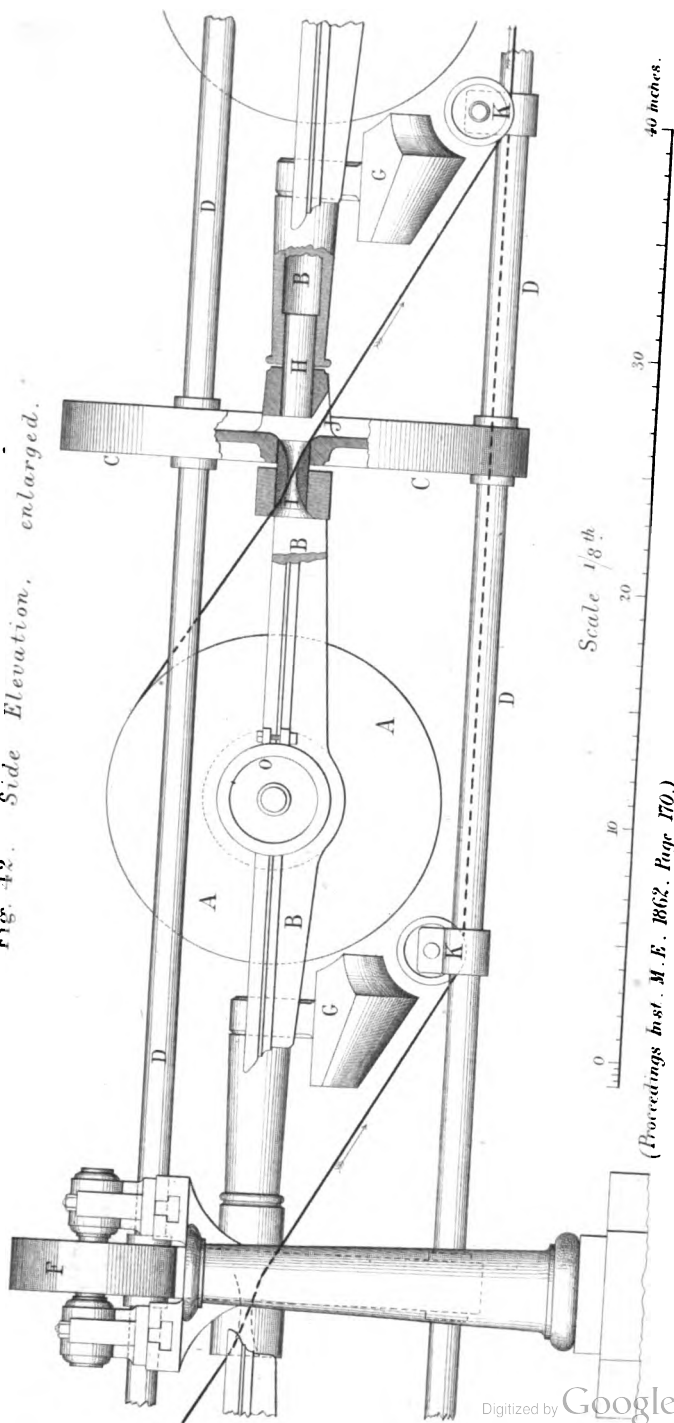
12 Feet.

ROPE MANUFACTURE.

Plate 61.

Smith's Wire Rope Machine.

Fig. 42. Side Elevation, enlarged.



(Proceedings Inst. M.E., 1862, Page 170.)

ROPE MANUFACTURE.

Plate 62.

Smith's Wire Rope Machine.

Fig. 43. Transverse Section.

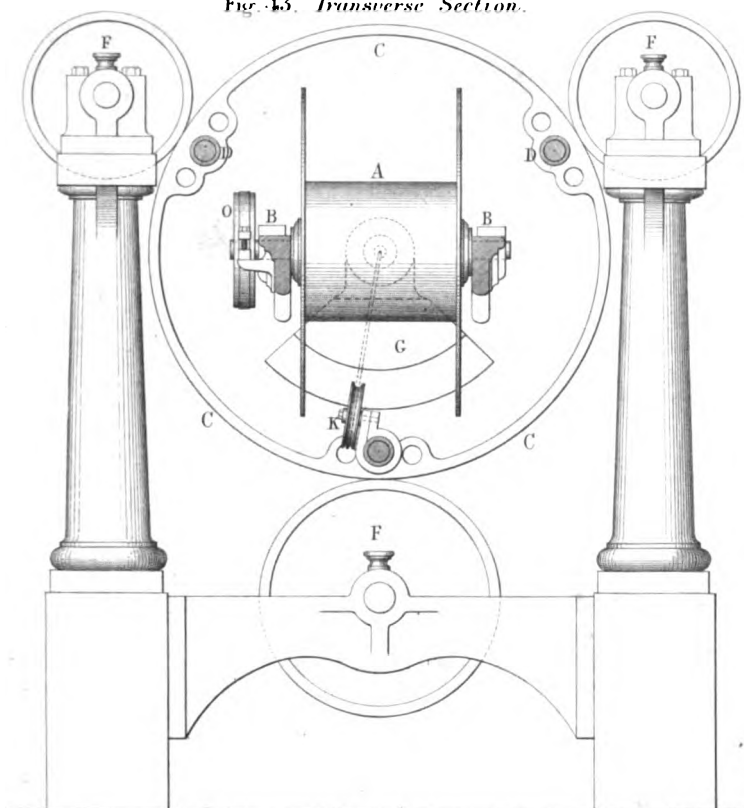
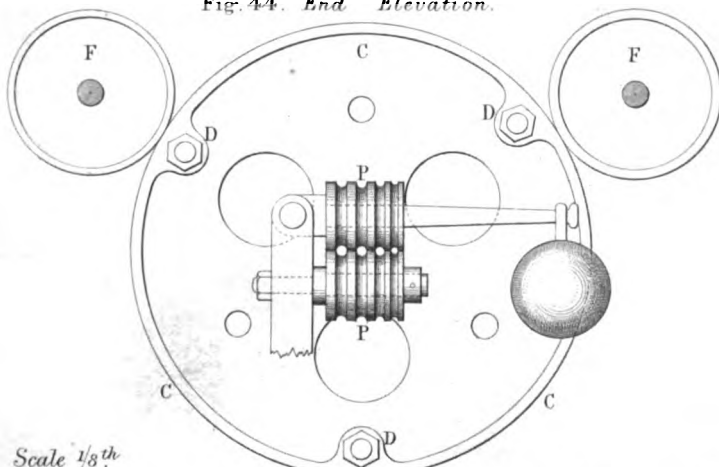


Fig. 44. End Elevation.



Scale $\frac{1}{8}^{th}$

0 5 10 15 20 25 30 Inches.

SUBMARINE TELEGRAPH CABLES. Plate 63.
Malta and Alexandria. 1861.

Fig 1.

Main Cable.

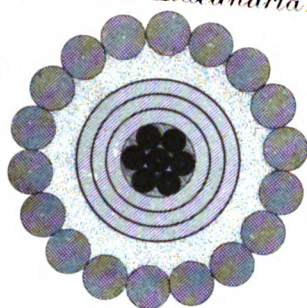


Fig 2.

Shore End.

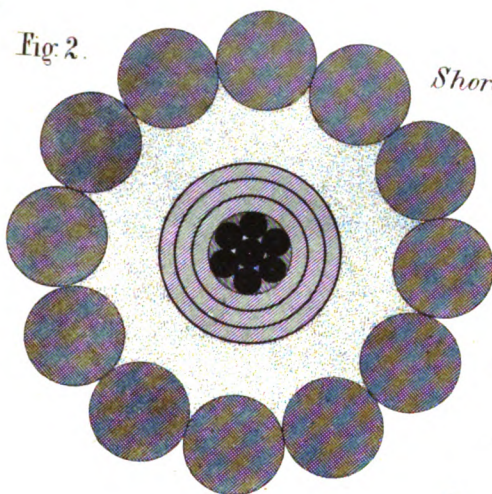


Fig 3. *Longitudinal view.*

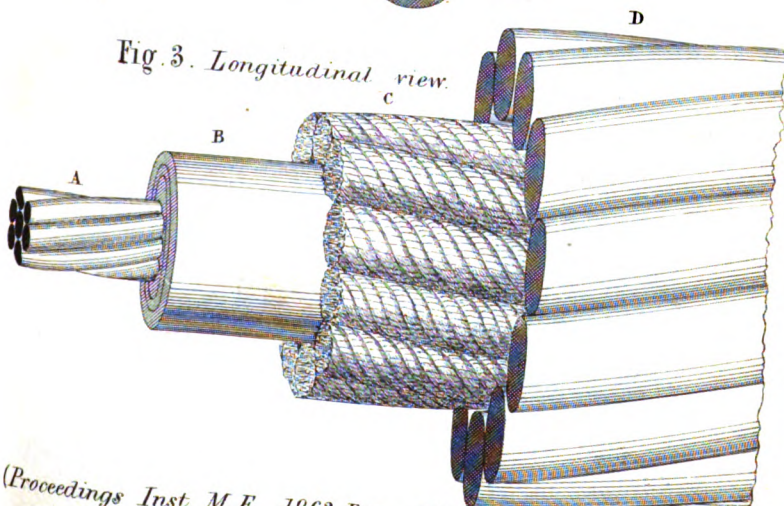


Fig 4. *Spezzia and Corsica* 1854.

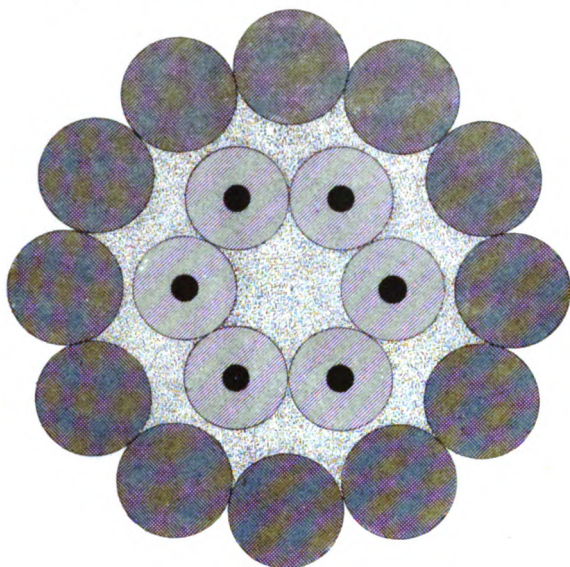


Fig 5.
Varna and Balaclava.
1855.

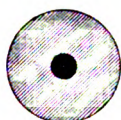


Fig 6 *Atlantic.* 1857.

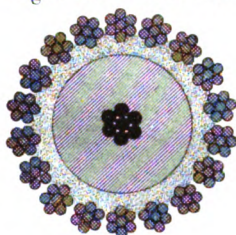


Fig 8.
Toulon and Algiers. 1860.

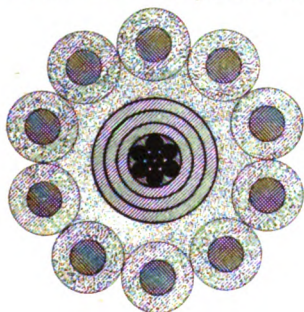
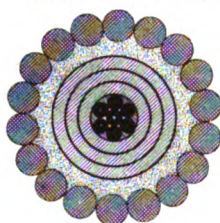


Fig. 7.
Red Sea. 1859.



SUBMARINE TELEGRAPH CABLES. *England and Holland. 1862.* *Plate 65.*

Fig. 9.

Main Cable.

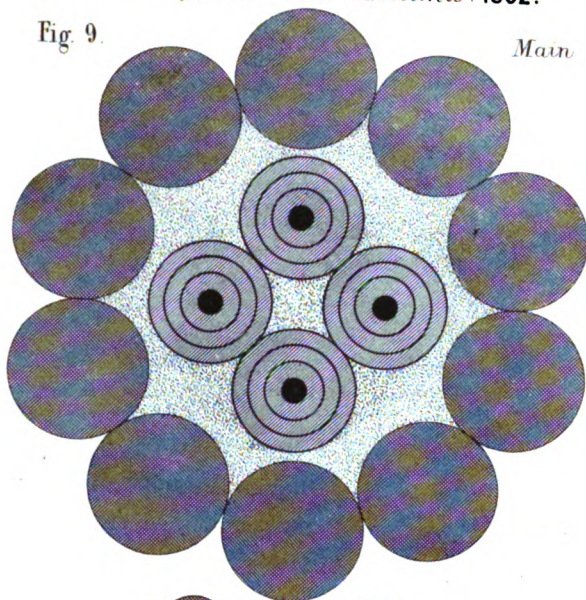


Fig. 10.

Shore End.

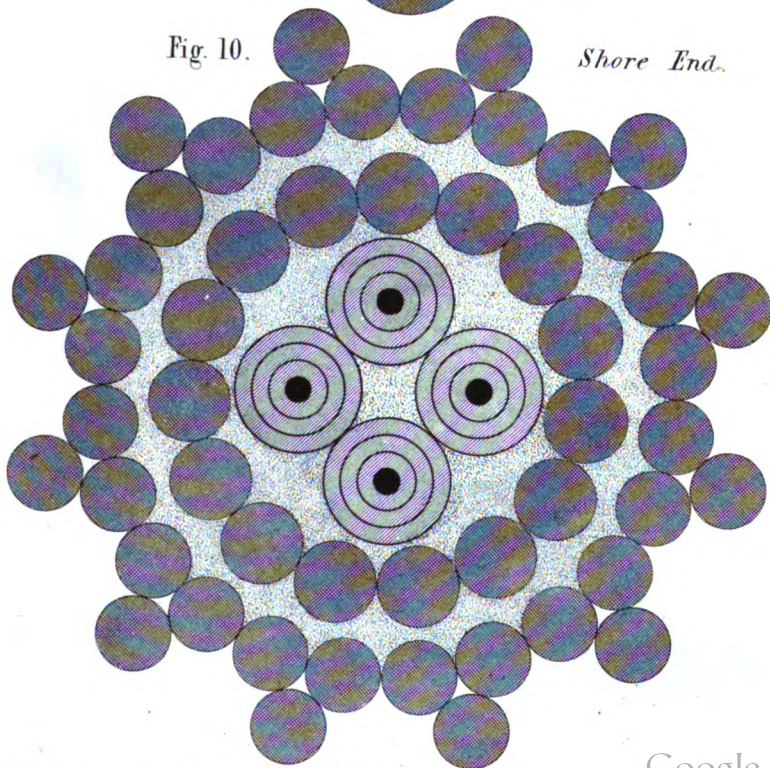


Fig. 11. *Iste of Man.* 1859.

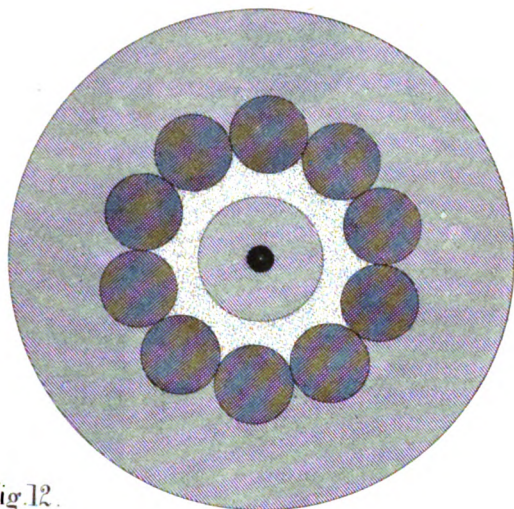


Fig. 12.

Chatterton's Cable 1862.

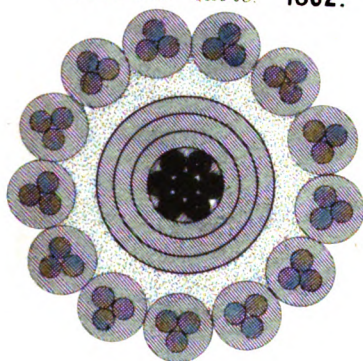


Fig. 13.

Allan's Cable 1862.

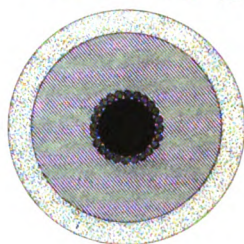
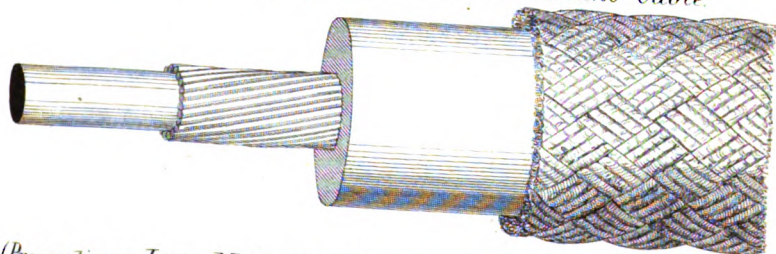


Fig. 14. *Longitudinal view of Allan's Cable*

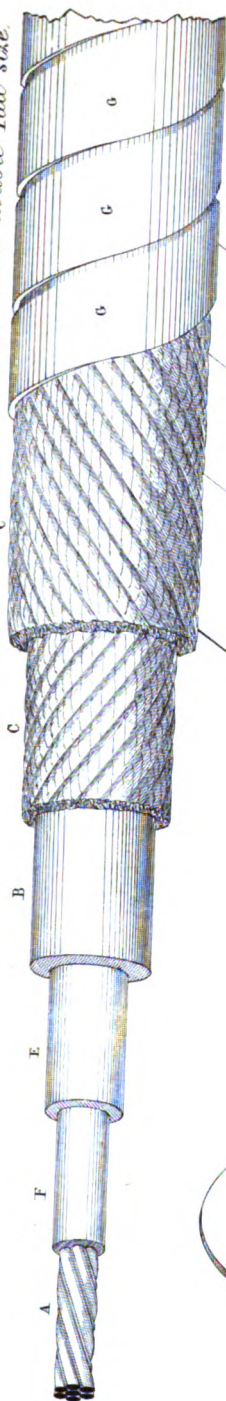


(*Proceedings Inst. M.E.* 1862. Page 211) Scale double full size

SUBMARINE TELEGRAPH CABLES.

Plate 67.

Fig 15. Longitudinal view of Siemens' Cable. 1862. Scale double full size.



Section of
Copper Conducting Core.



Fig 18. Strand Machine.

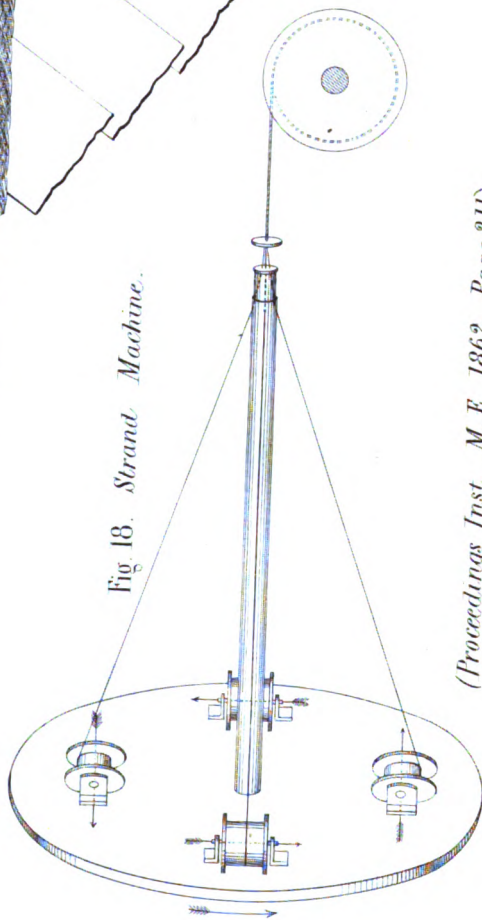
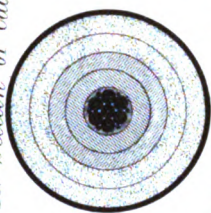


Fig 17

Scale six times full size.

Fig 16. Section of Cable.



Scale double full size.

(Proceedings Inst. M.E. 1862. Page 211)

*Sheathing Machine
for Siemens' Cable.*

Fig. 19. Longitudinal Section.

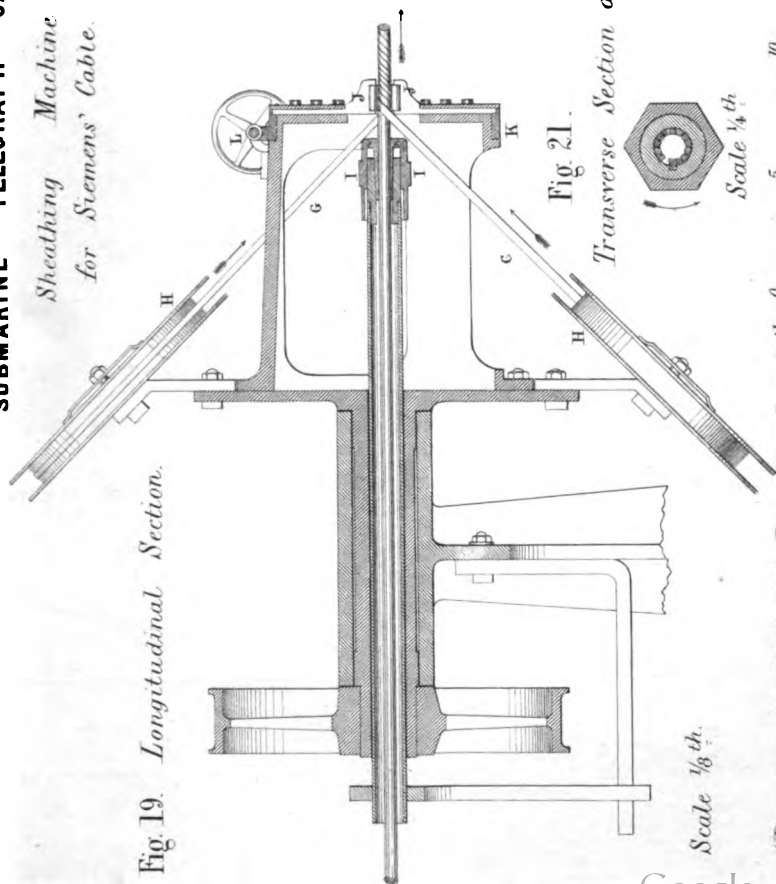


Fig. 20.
End Elevation.

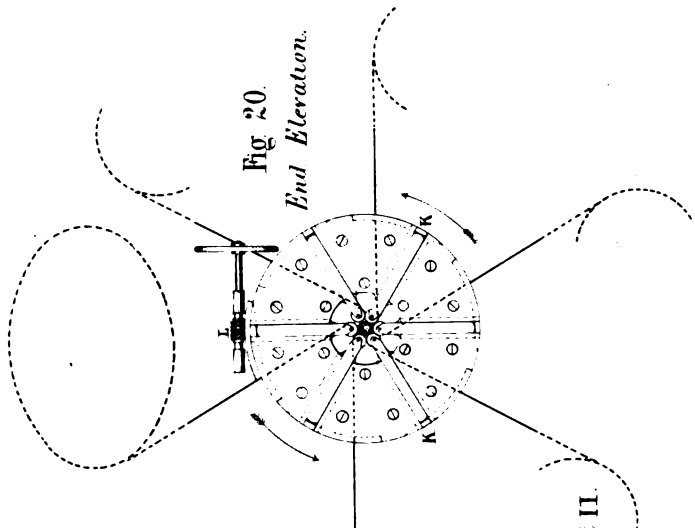
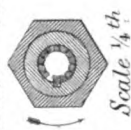


Fig. 21.
Transverse Section at II.



DOUBLE CYLINDER ENGINES. *Plate 69.*

*Theoretical Diagrams of Comparative Initial Blow
and Motive Force throughout stroke,
in Single and Double Cylinder Engines
of equal power and expanding SIX times.*

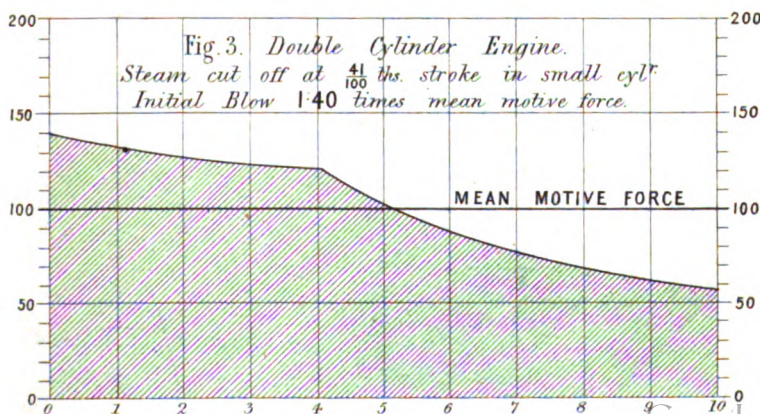
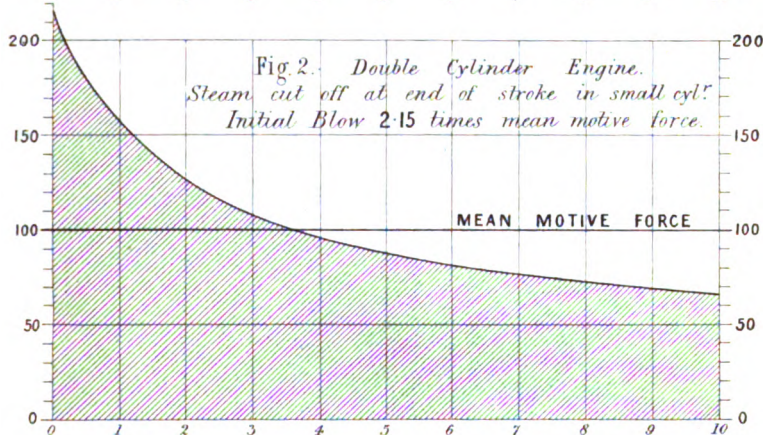
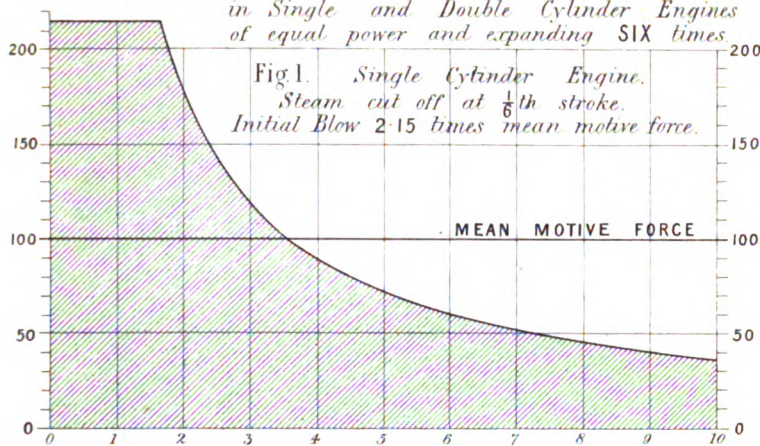
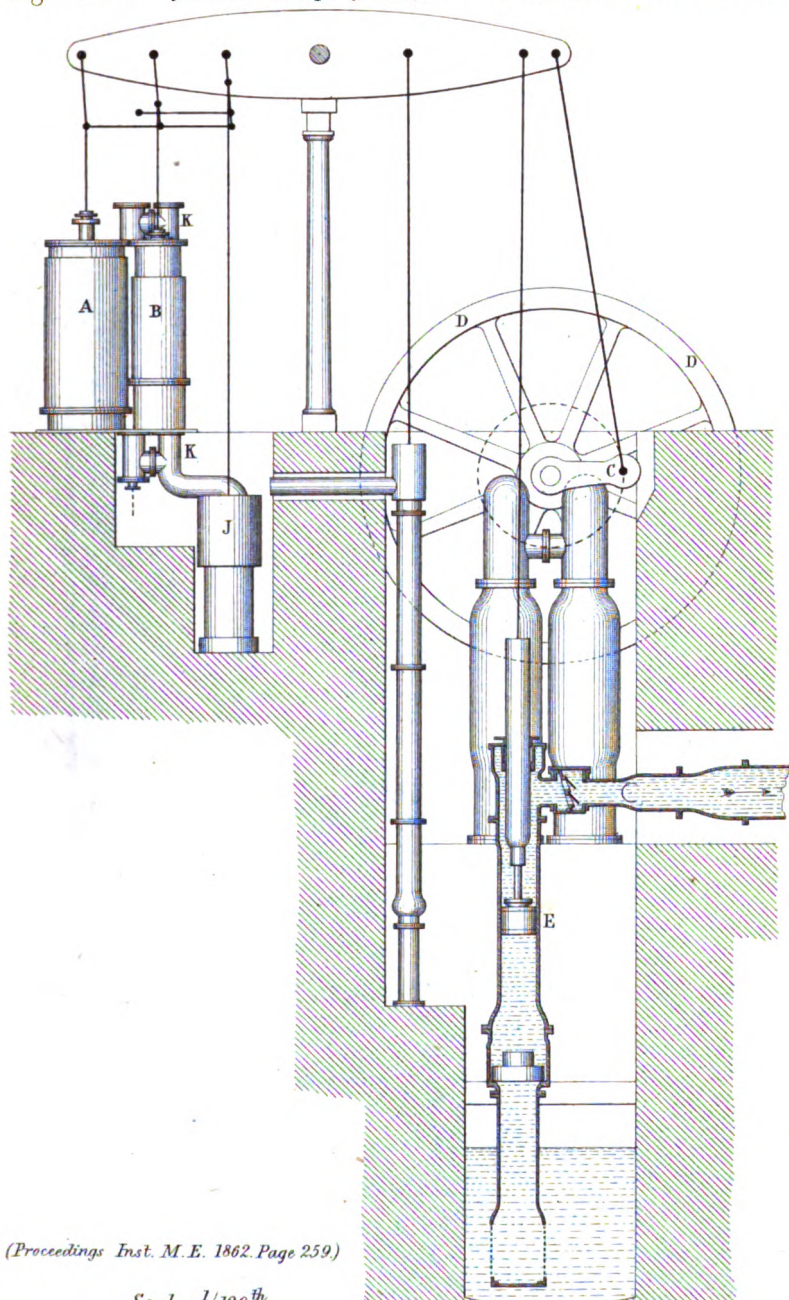


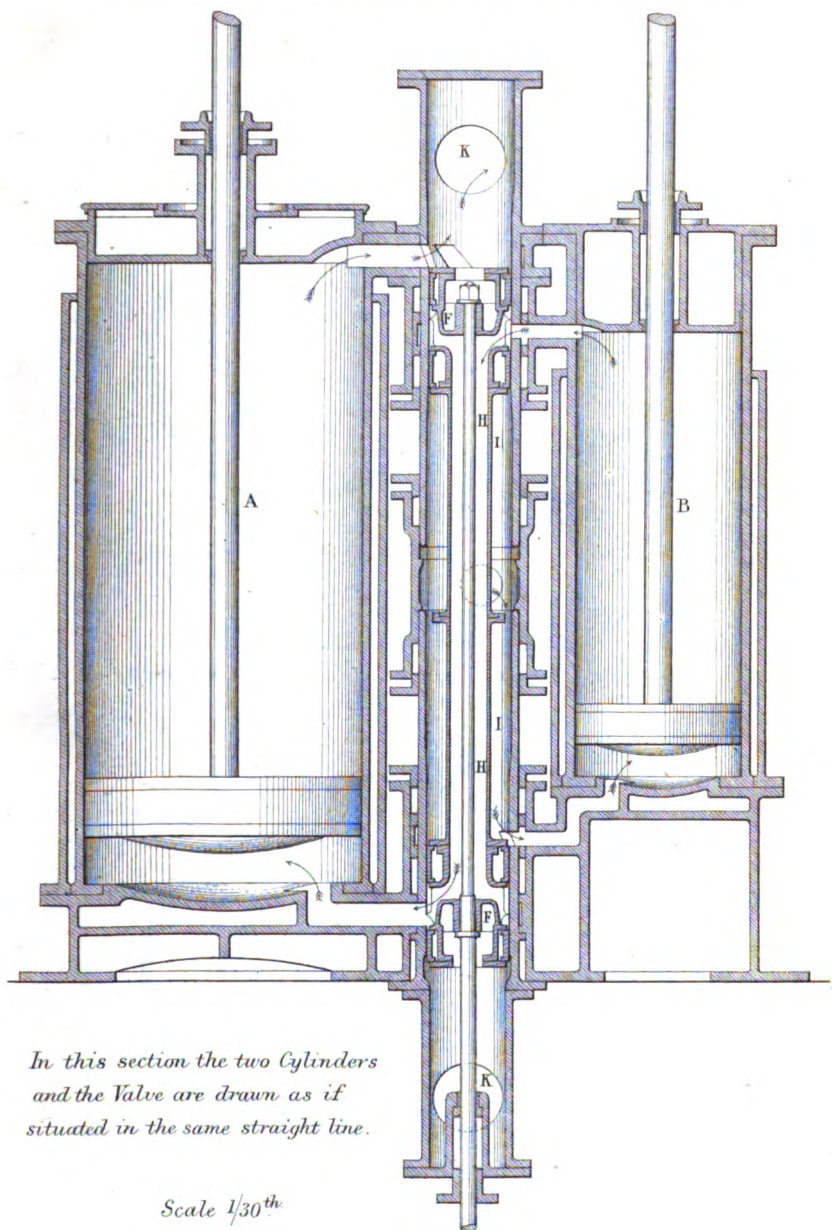
Fig.1. Double Cylinder Pumping Engines at Lambeth Water Works.



(Proceedings Inst. M.E. 1862. Page 259.)

Scale $\frac{1}{120}^{th}$.

Fig. 2. *Vertical Section of Cylinders and Valve.*



*In this section the two Cylinders
and the Valve are drawn as if
situated in the same straight line.*

Scale $\frac{1}{30}^{th}$

10 0 10 20 30 40 50 60 70 80 90 100 Inches.
(Proceedings Inst. M.E. 1862. Page 259.)

Fig. 3. *Sectional Plan
through steam port of Large cylinder.*

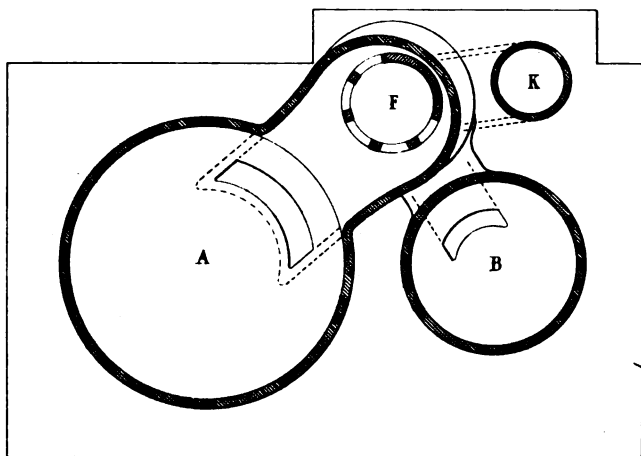
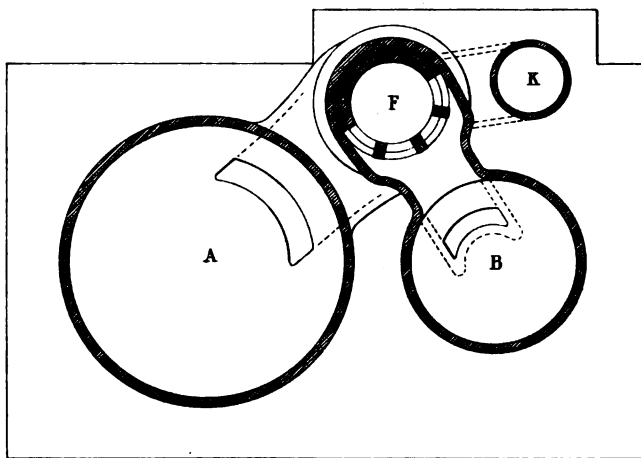


Fig. 4. *Sectional Plan
through steam port of Small cylinder.*



Scale $\frac{1}{30}^{th}$.

10 0 10 20 30 40 50 60 70 80 90 100 Inches.

(Proceedings Inst. M.E. 1862. Page 259.)

DOUBLE CYLINDER ENGINES.

Fig. 5.

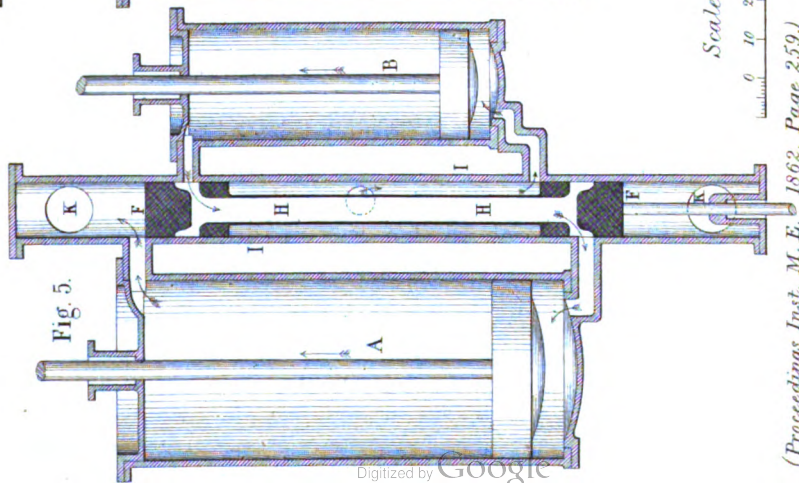


Fig. 6.

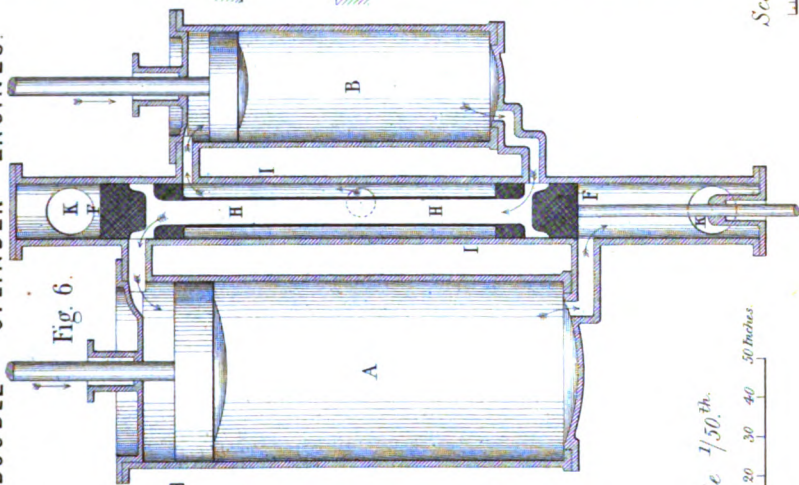
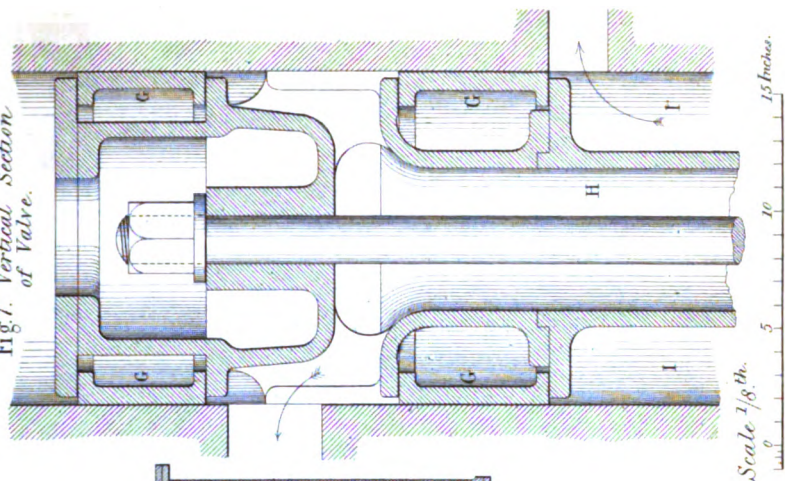


Fig. 7. Vertical Section of Valve.



Indicator Diagrams from Lambeth Water Works Engines.

Fig. 8. *Indicator Diagrams taken simultaneously from Bottom of Small cylinder and Top of Large cylinder.*

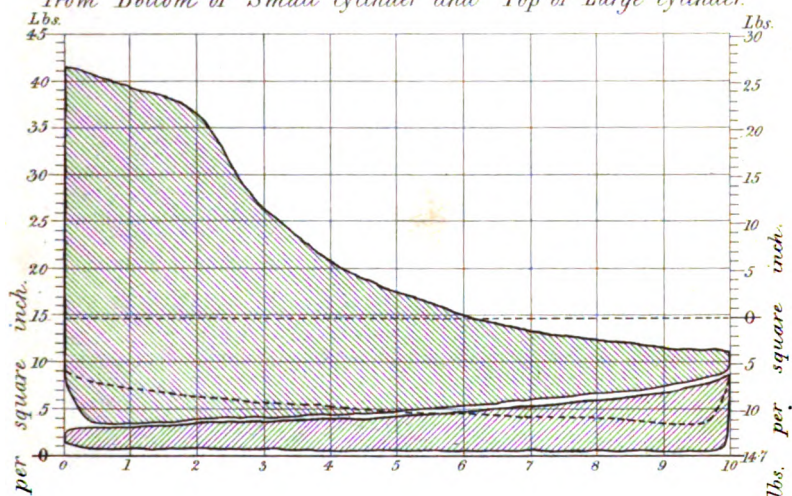


Fig. 9. *Indicator Diagrams taken simultaneously from Top of Small cylinder and Bottom of Large cylinder.*

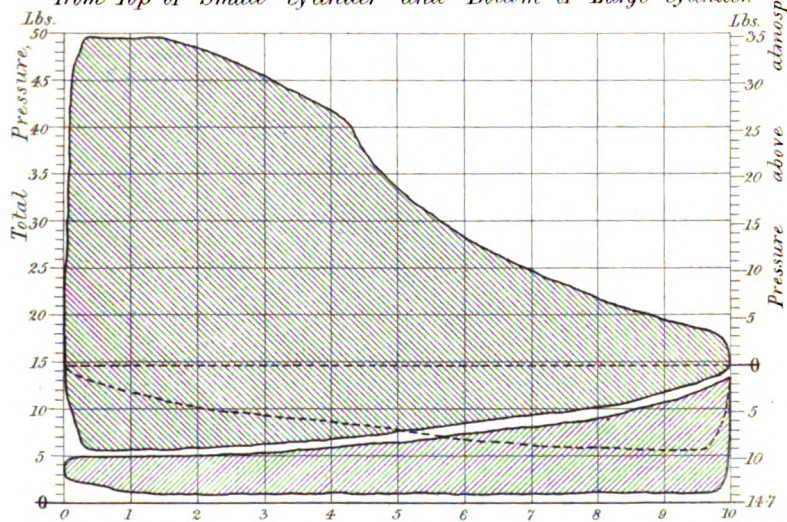


Fig 10. *Indicator Diagram from Top of Small cylinder, taken simultaneously with Fig. 8.*

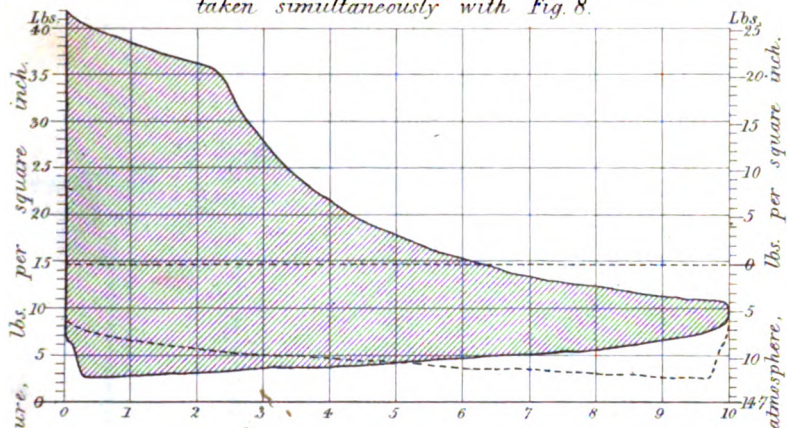


Fig. II. *Indicator Diagram from Top of Large cylinder, taken simultaneously with Fig. 9.*

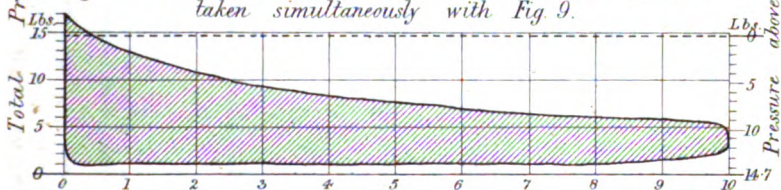
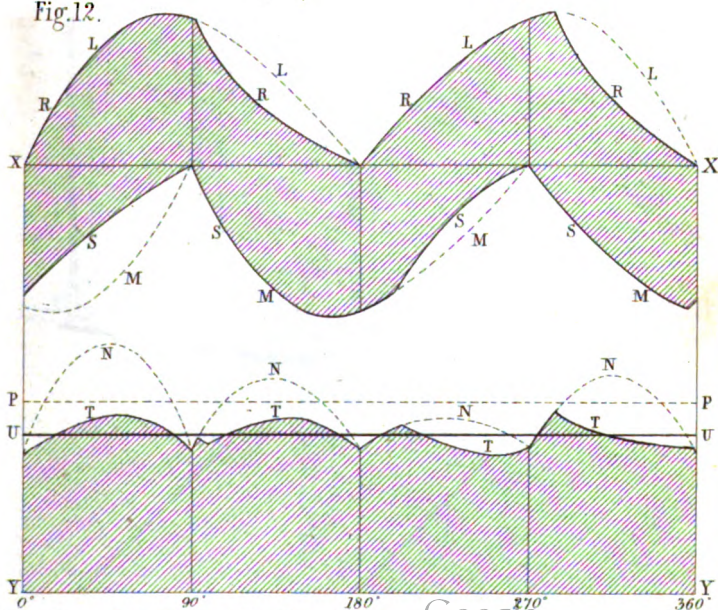


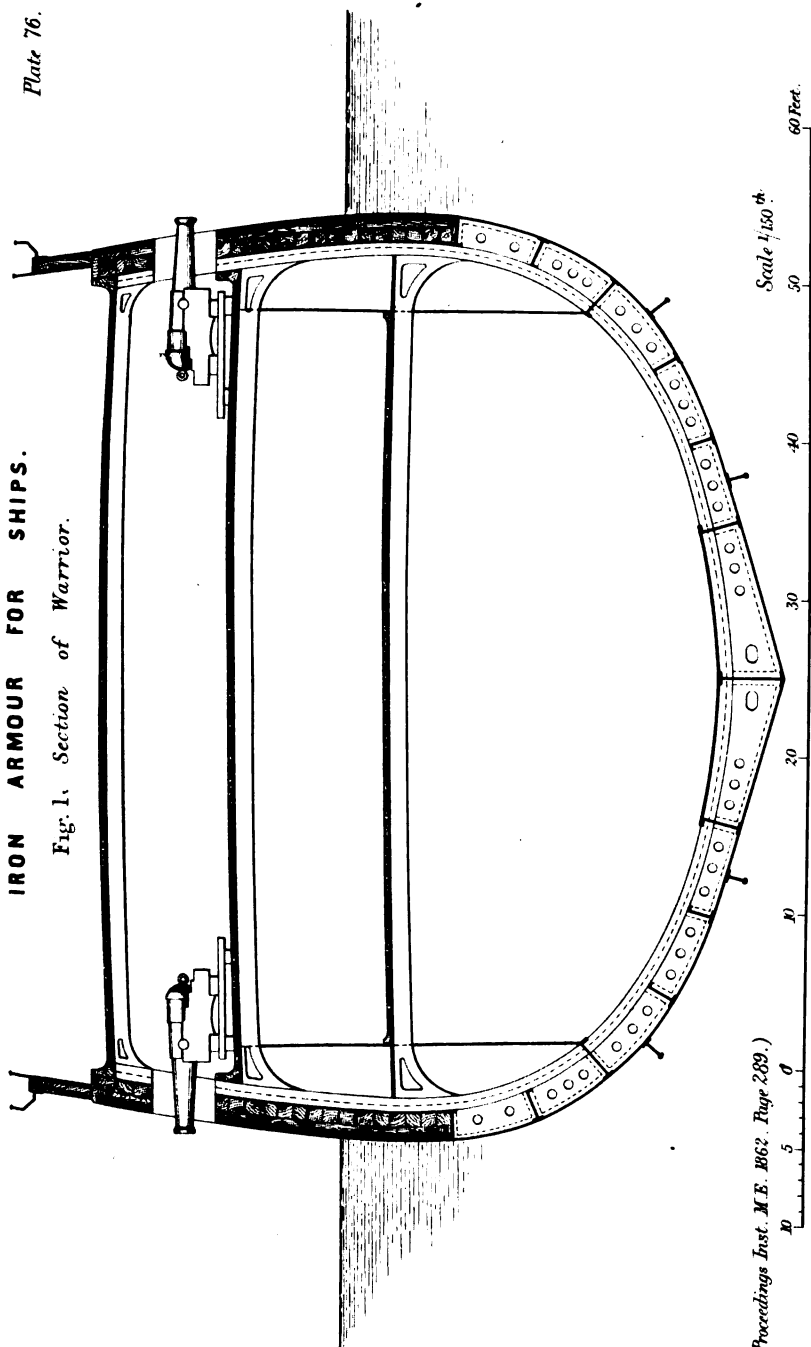
Fig. 12.



IRON ARMOUR FOR SHIPS.

Plate 76.

Fig. 1. Section of *Warrior*.



(Proceedings Inst. M.E. 1862, Page 289.)

Fig. 2. *La Gloire*.

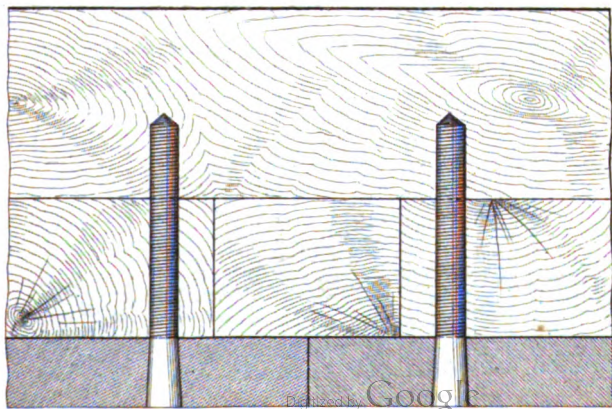


Fig. 3. *Warrior*.

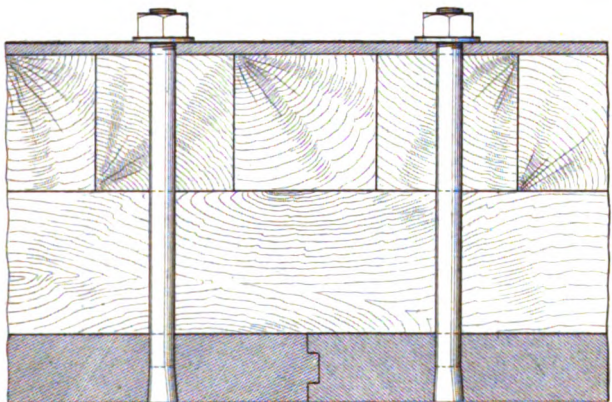
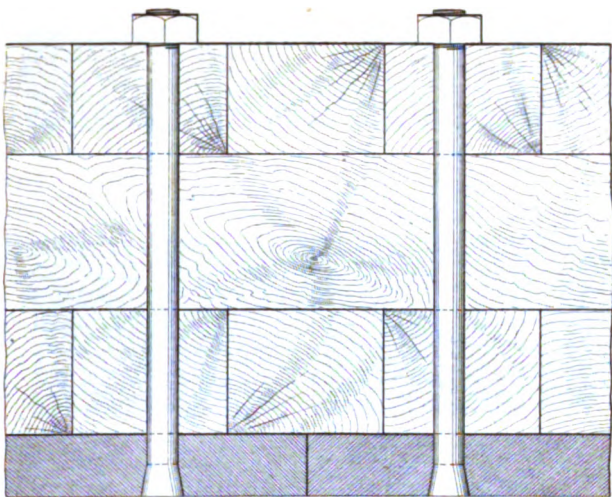


Fig. 4. *Trusty*.



Scale $1\frac{1}{2}$ inches.

IRON ARMOUR FOR SHIPS.

Plate 78.

Fig. 5.

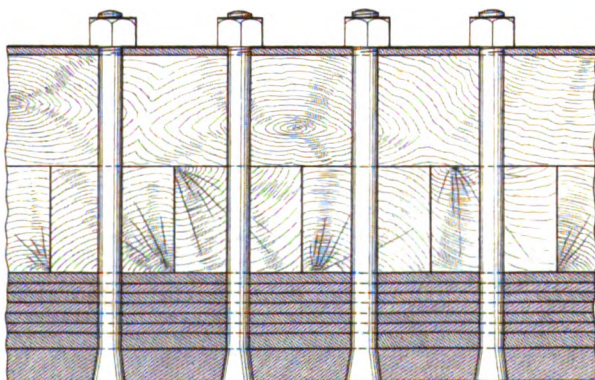


Fig. 6. *Merrimac*.

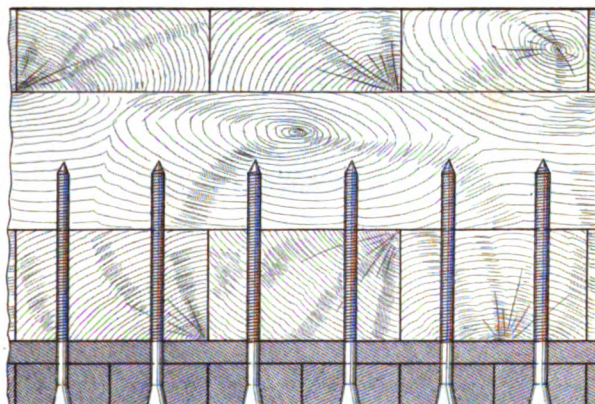


Fig. 7.

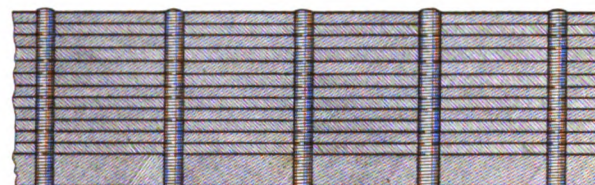


Fig. 8.



Scale $\frac{1}{12}$ in. 10 5 0 10 20 30 inches.

(Proceedings Inst. M.E., 1862, Page 289.)

Fig. 9.

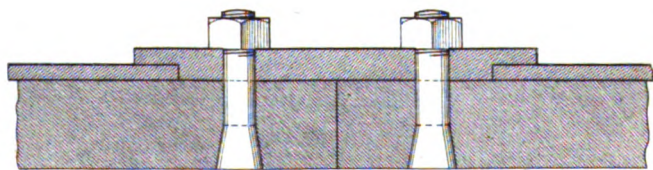
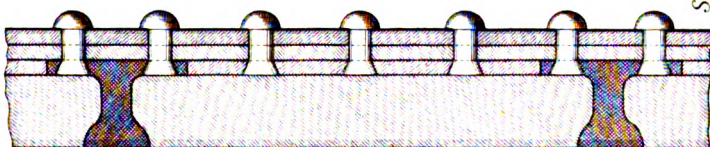


Fig. 10.



Scale $\frac{1}{12}$ in.

Fig. 11.

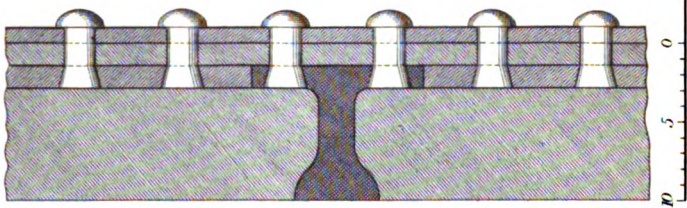
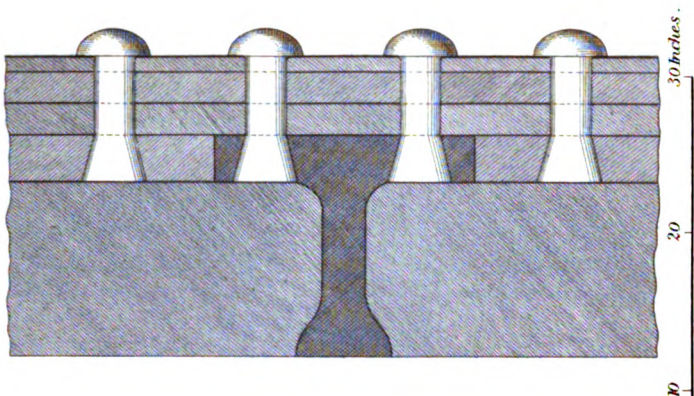


Fig. 12.



PACKING FOR PISTONS. *Plate 80.*

Locomotive Engine Piston with Steel Packing Rings.

Fig. 1. *Longitudinal Section.*

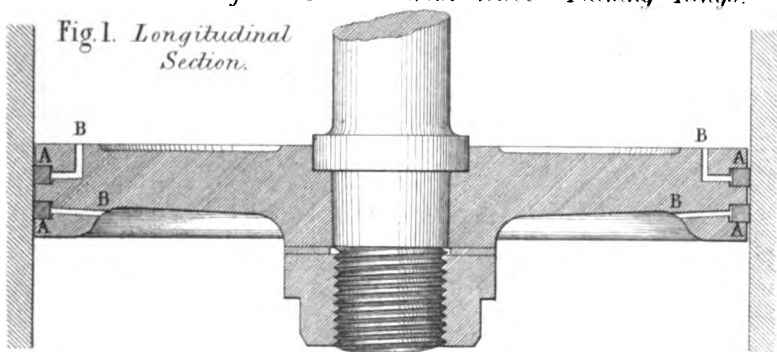


Fig. 2. *Plan.*

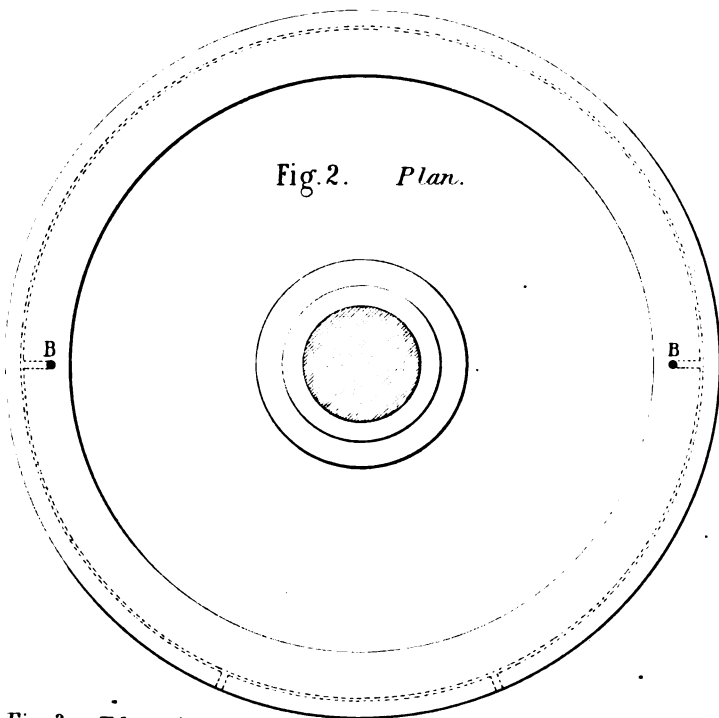
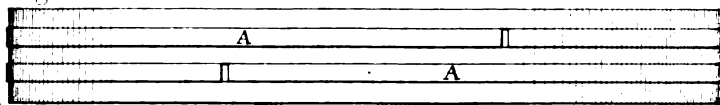


Fig. 3. *Elevation.*



Scale $\frac{1}{4}^{th}$.

5 10 15 Inches.

PACKING FOR PISTONS. *Plate 81.*

Locomotive Engine Piston with Brass Packing Rings.

Fig 4. *Longitudinal Section.*

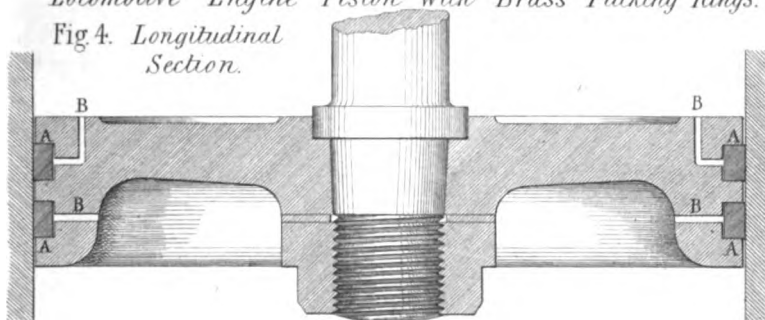


Fig 5. *Plan.*

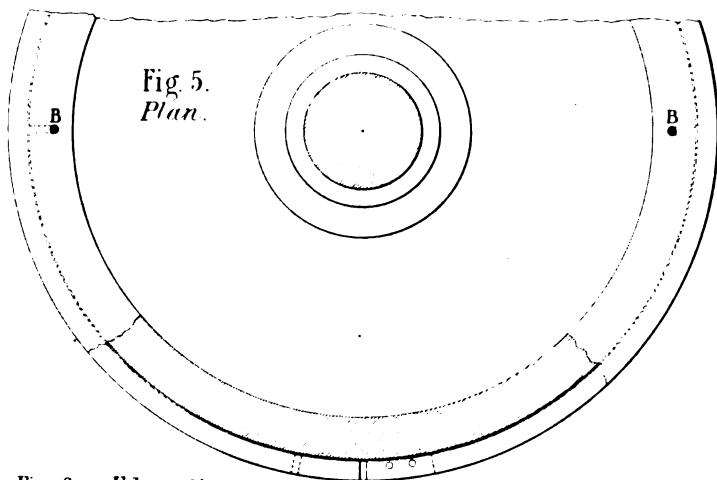


Fig 6. *Elevation.*

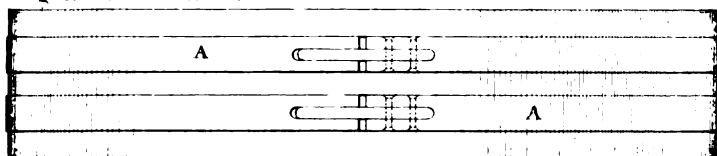
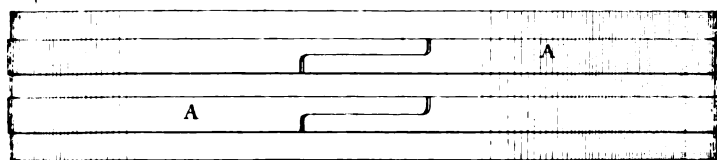


Fig 7. *Plan.*



*Packing Rings
with
Lapped Joint.*

Fig 8. *Elevation.*



Stationary Engine Piston.

Fig 9. *Longitudinal Section.*

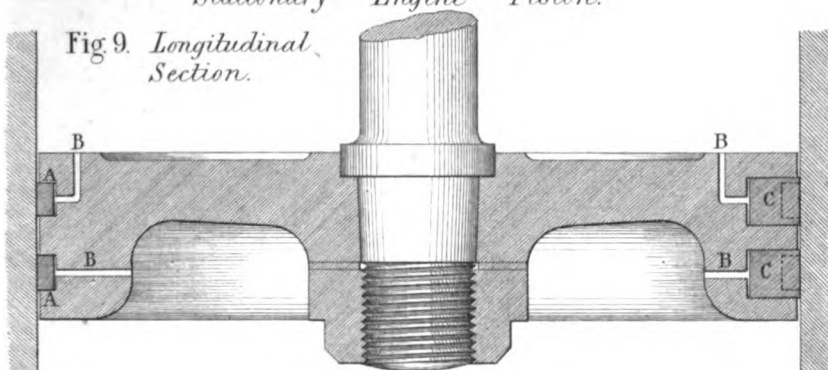


Fig 10. *Plan.*

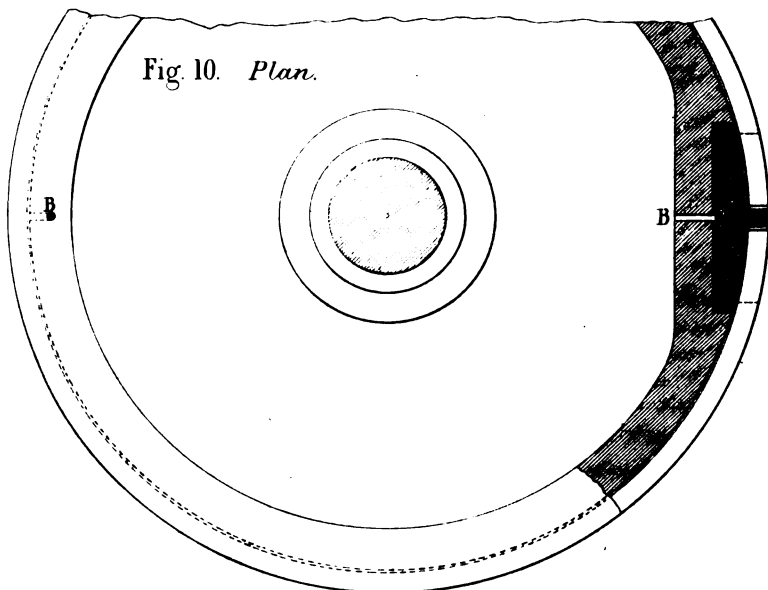
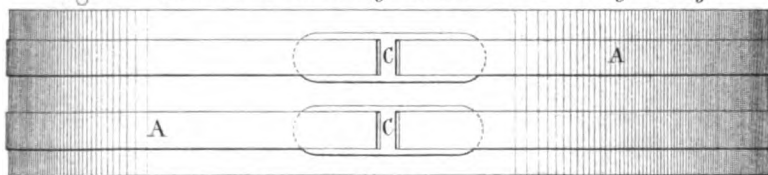


Fig 11. *Elevation showing Joint of Packing Rings.*



Scale $\frac{1}{4}$ th.

0 5 10 15Inches.

PACKING FOR PISTONS.

Plate 83.

Fig. 12. Double-acting

Pump Bucket.

Scale $\frac{1}{3}^{rd}$.

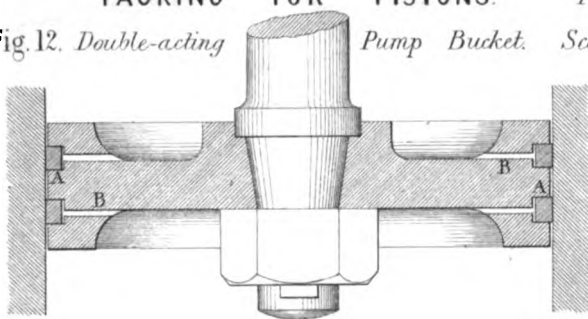


Fig. 13. Single-acting

Pump Bucket.

Scale $\frac{1}{3}^{rd}$.

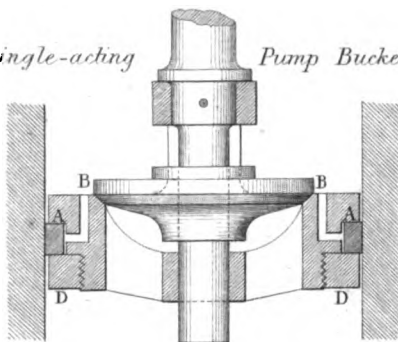
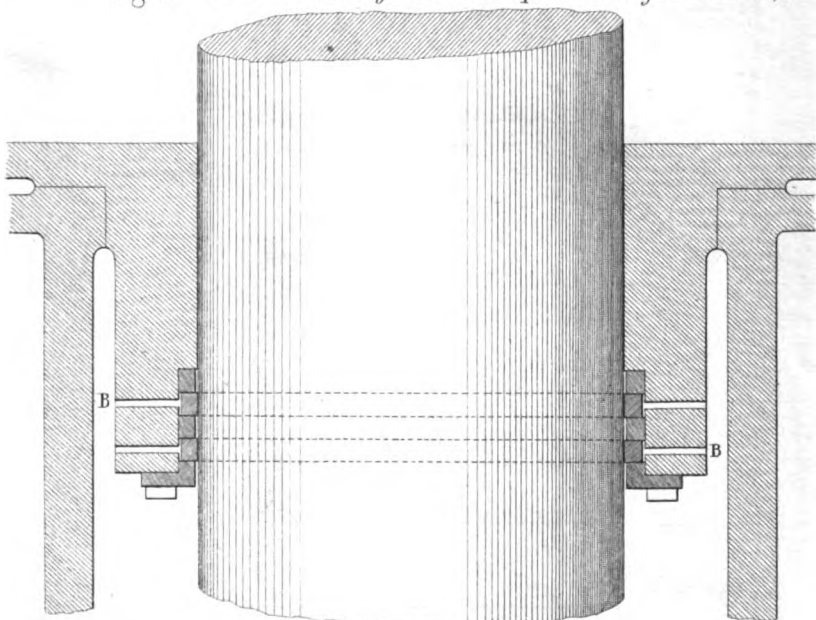
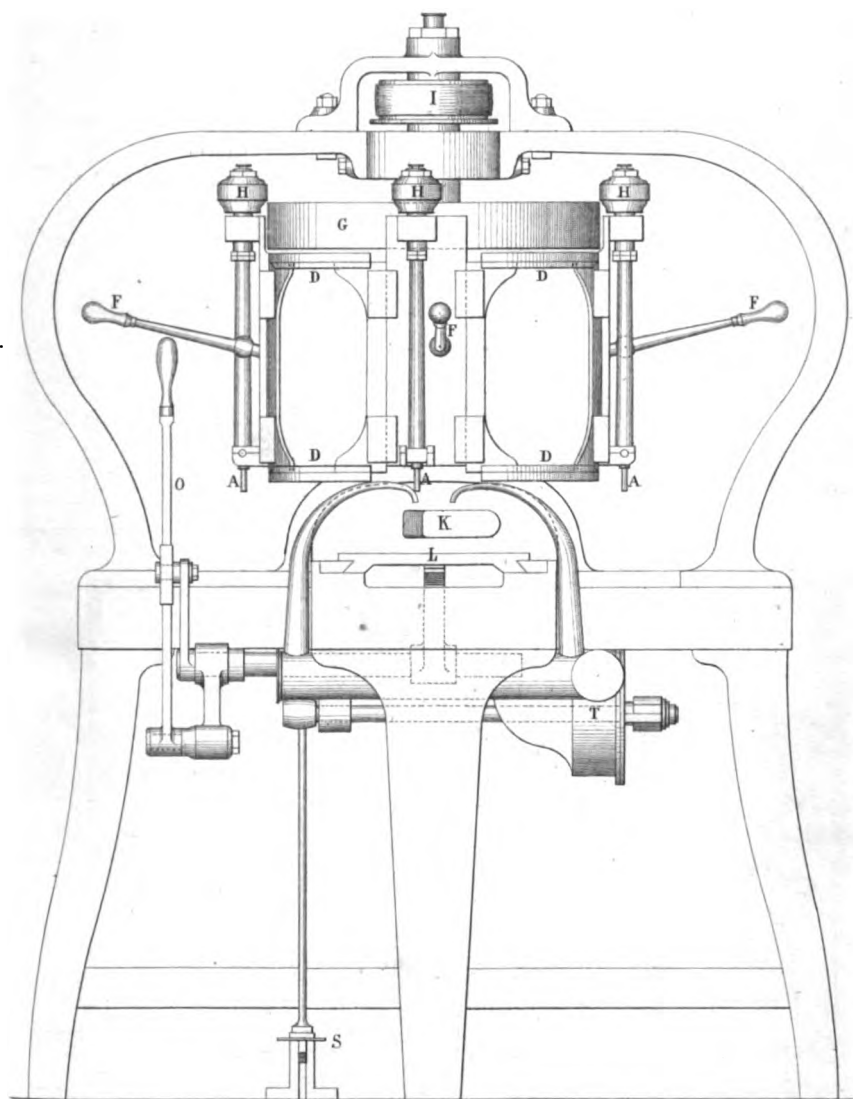


Fig. 14. Gland Packing for Pump Plunger. Scale $\frac{1}{4}^{th}$.



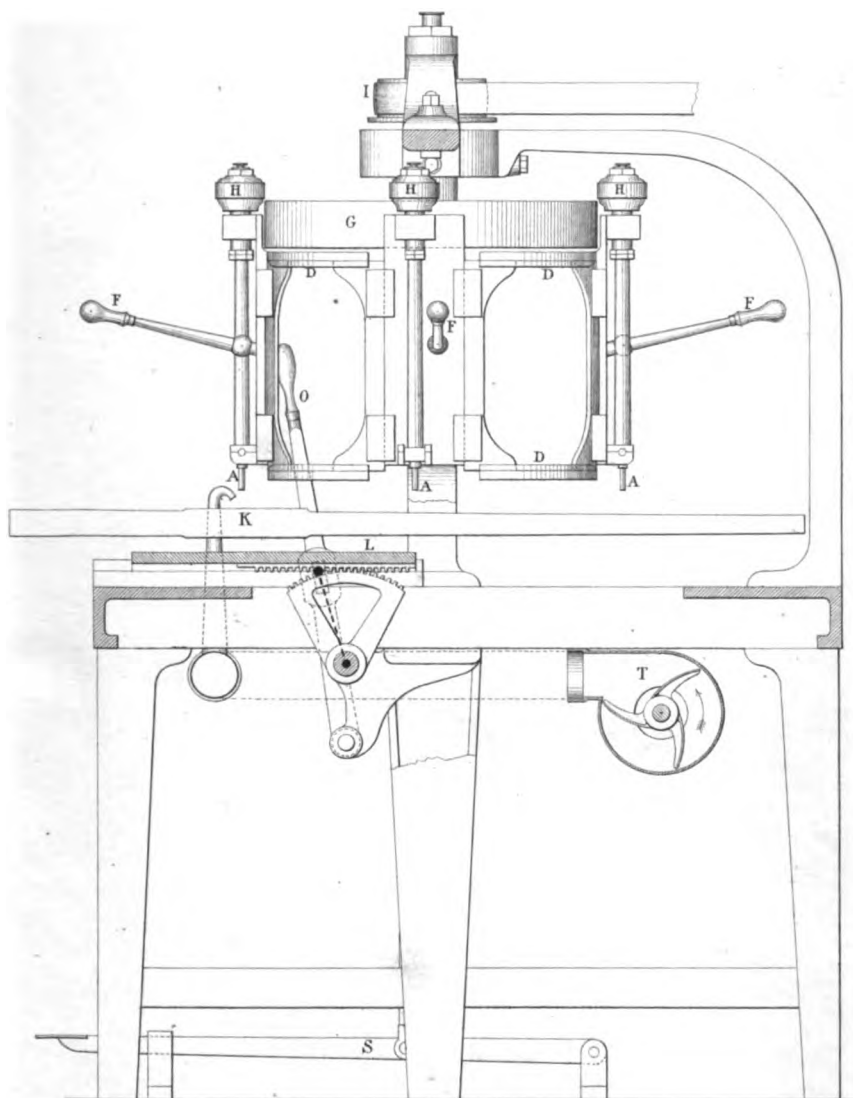
LOCK BEDDING MACHINE.

Fig 1. *Front Elevation.*Scale $\frac{1}{12}$ th.

10 5 0 10 20 30 Inches.

LOCK BEDDING MACHINE.

Fig2. Side Elevation, partly section..



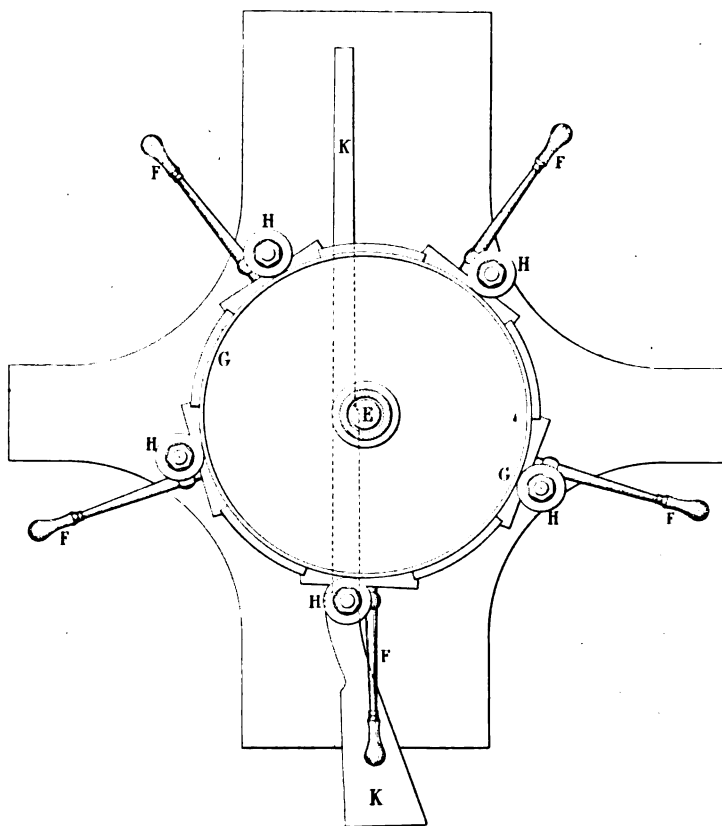
Scale $\frac{1}{12}^{th}$.

10 5 0 10 20 30 inches.

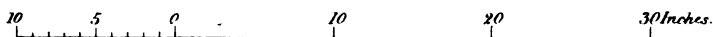
(Proceedings Inst. M.E. 1862 Page 328.)

LOCK BEDDING MACHINE.

Fig 3. Plan.



Scale $\frac{1}{12}^{th}$.

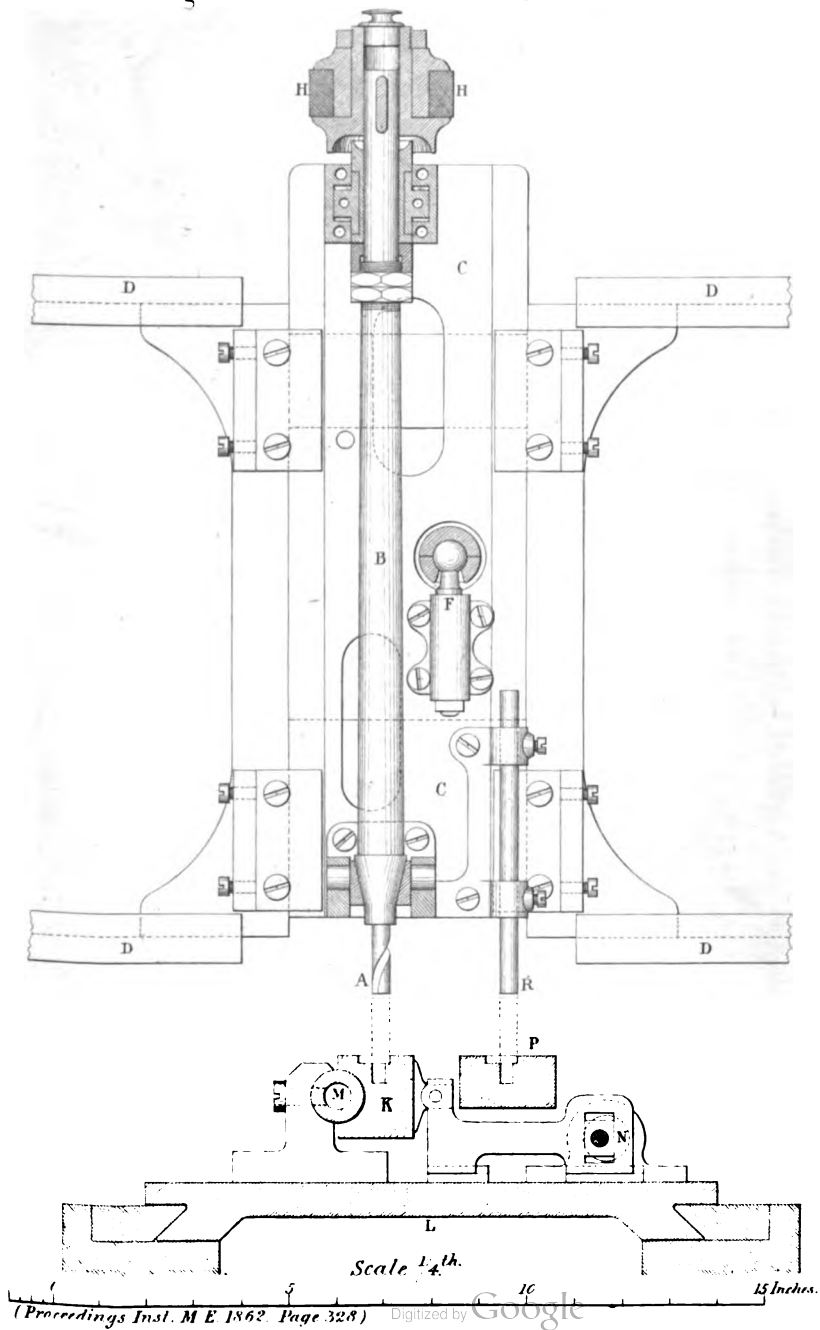


MACHINERY.

Plate 87.

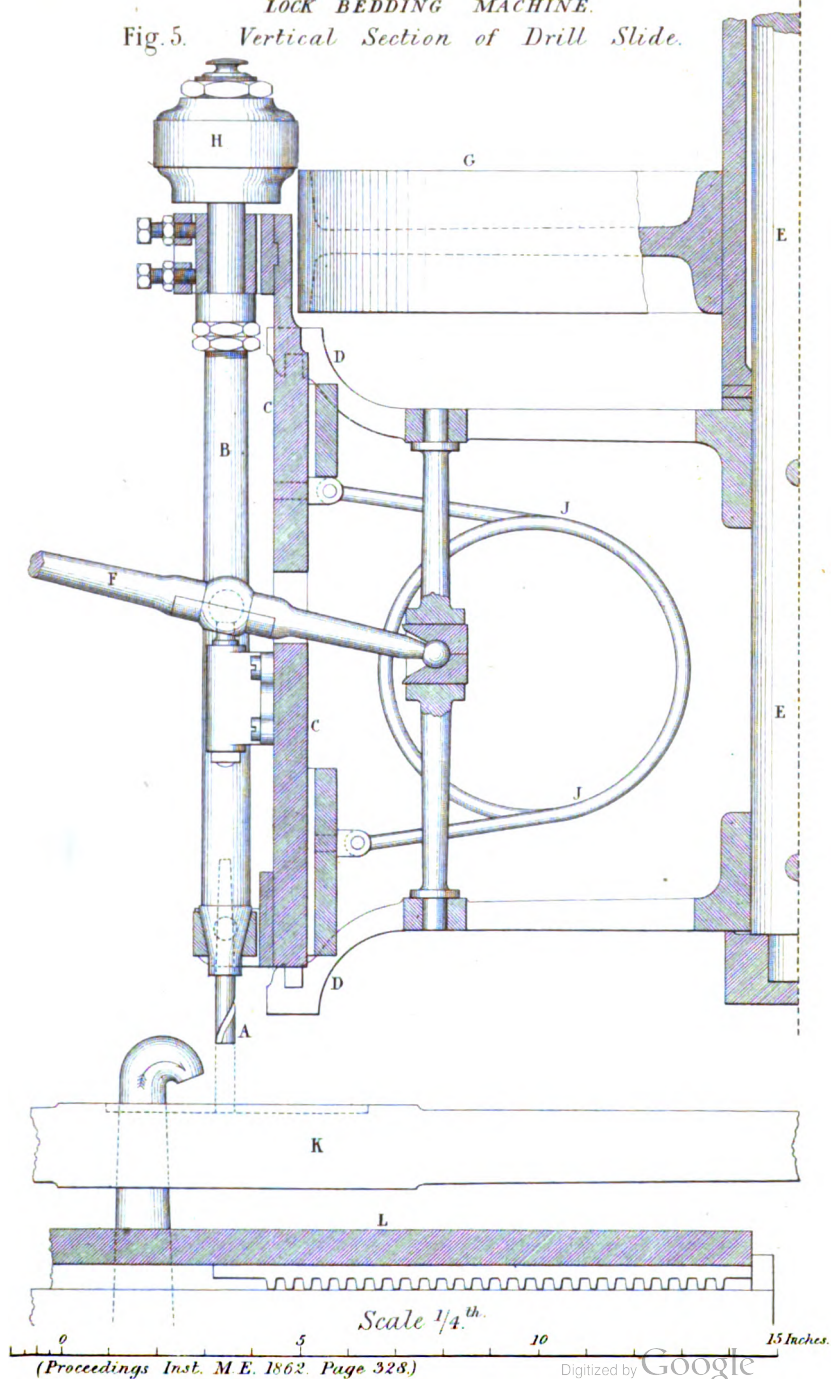
LOCK BEDDING MACHINE.

Fig. 4. *Front Elevation of Drill Slide.*



LOCK BEDDING MACHINE.

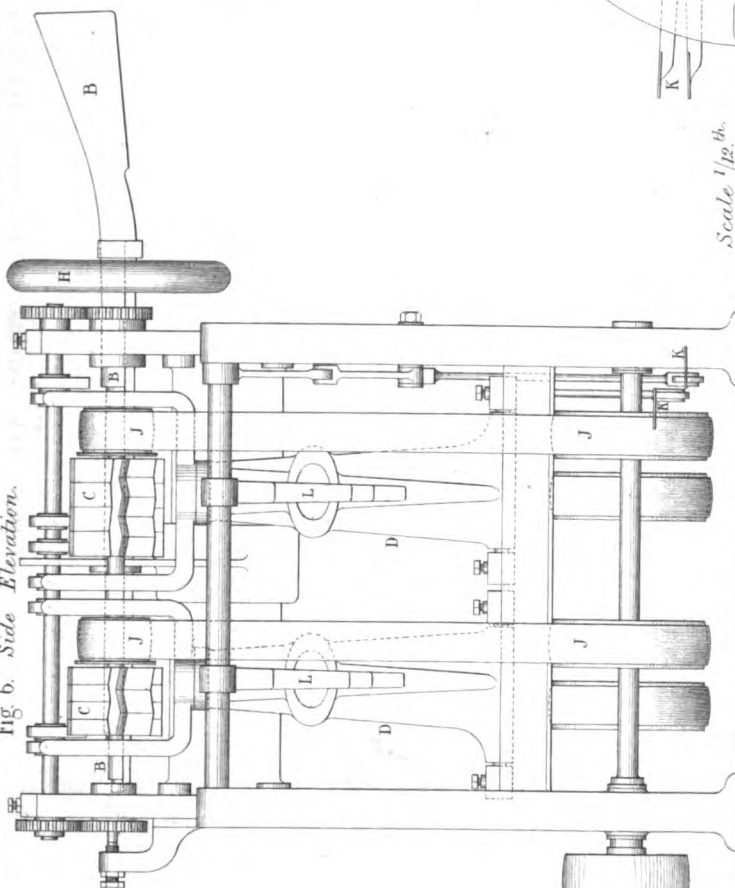
Fig. 5. Vertical Section of Drill Slide.



GUNSTOCK MACHINERY.
MACHINE FOR SHAPING GUNSTOCK BETWEEN BANDS

Plate 89.

Fig 6. Side Elevation.



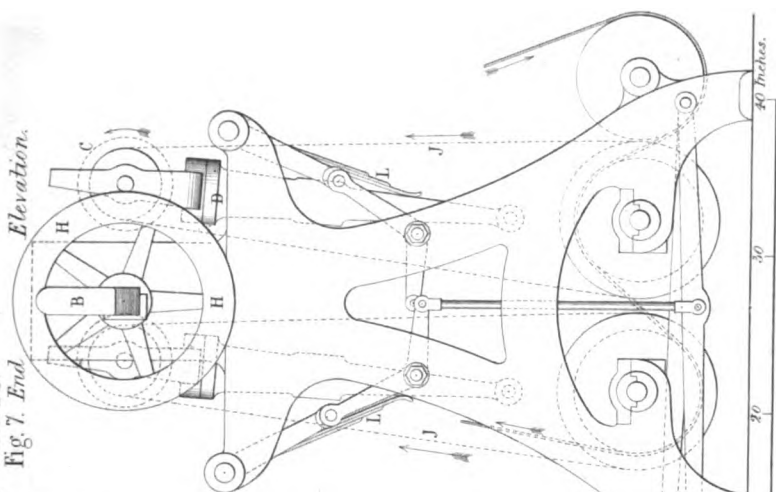
(Proceedings Inst. M.E. 1862, Page 328.)

Scale 1/12th.

0 5 10 20 30 40 Inches.

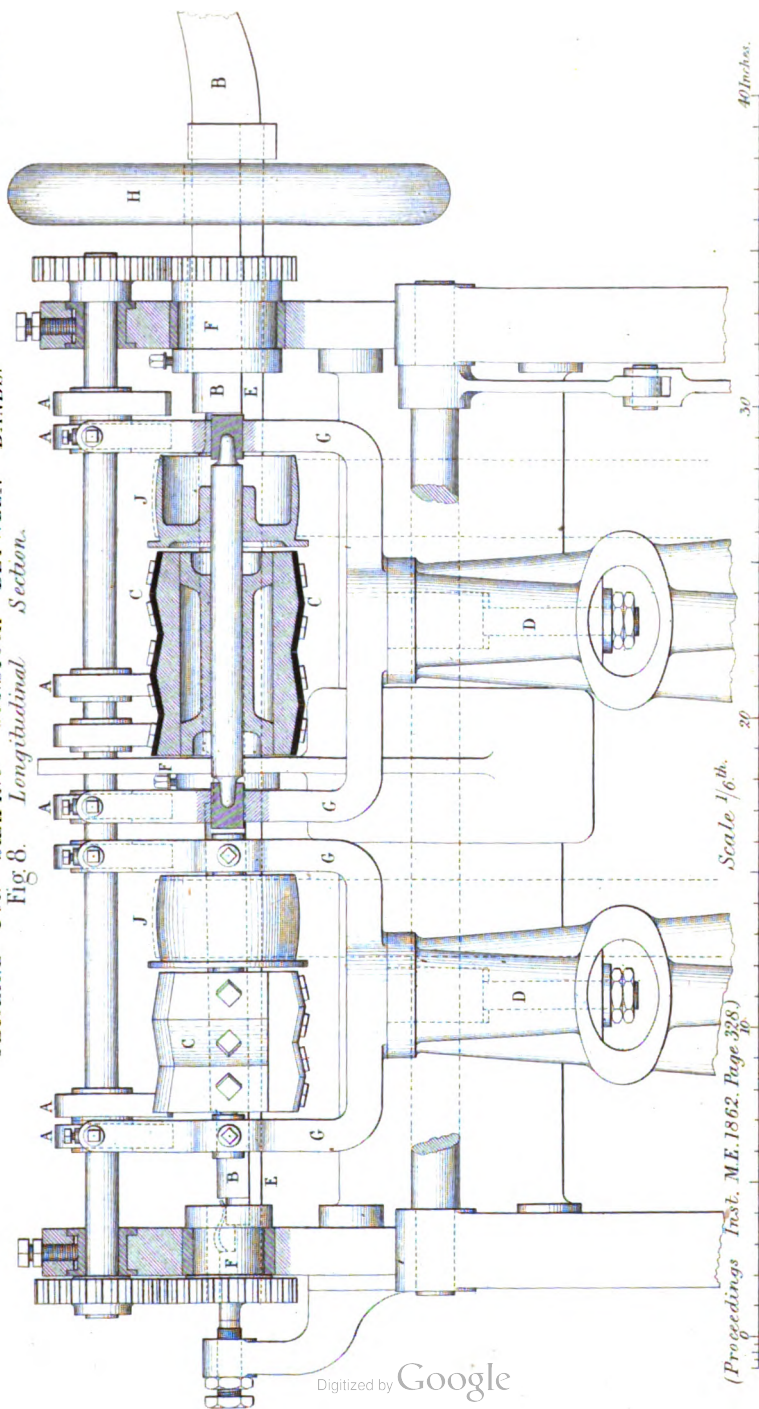
BANDS
Fig 7. End

Elevation.



GUNSTOCK MACHINERY.
MACHINE FOR SHAPING GUNSTOCK BETWEEN BANDS.

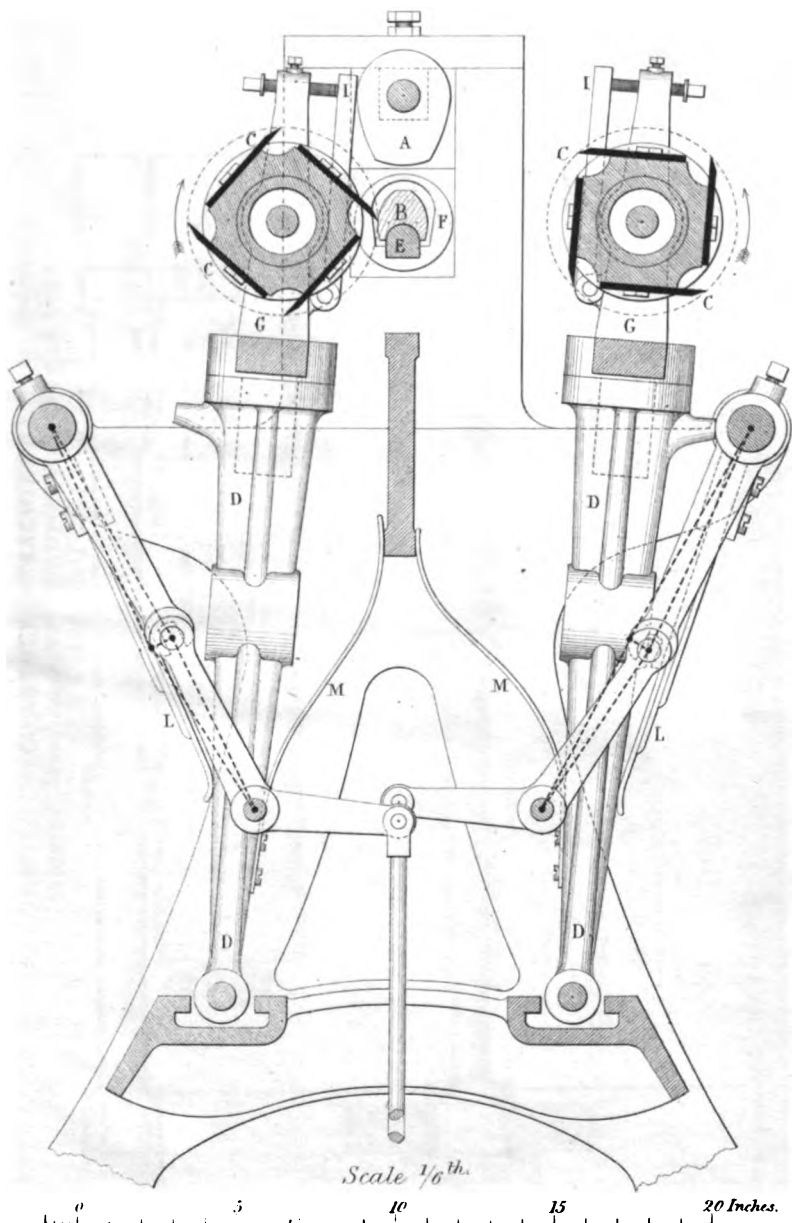
Fig. 8. *Longitudinal Section.*



(Proceedings Inst. M.E. 1862, Page 328)

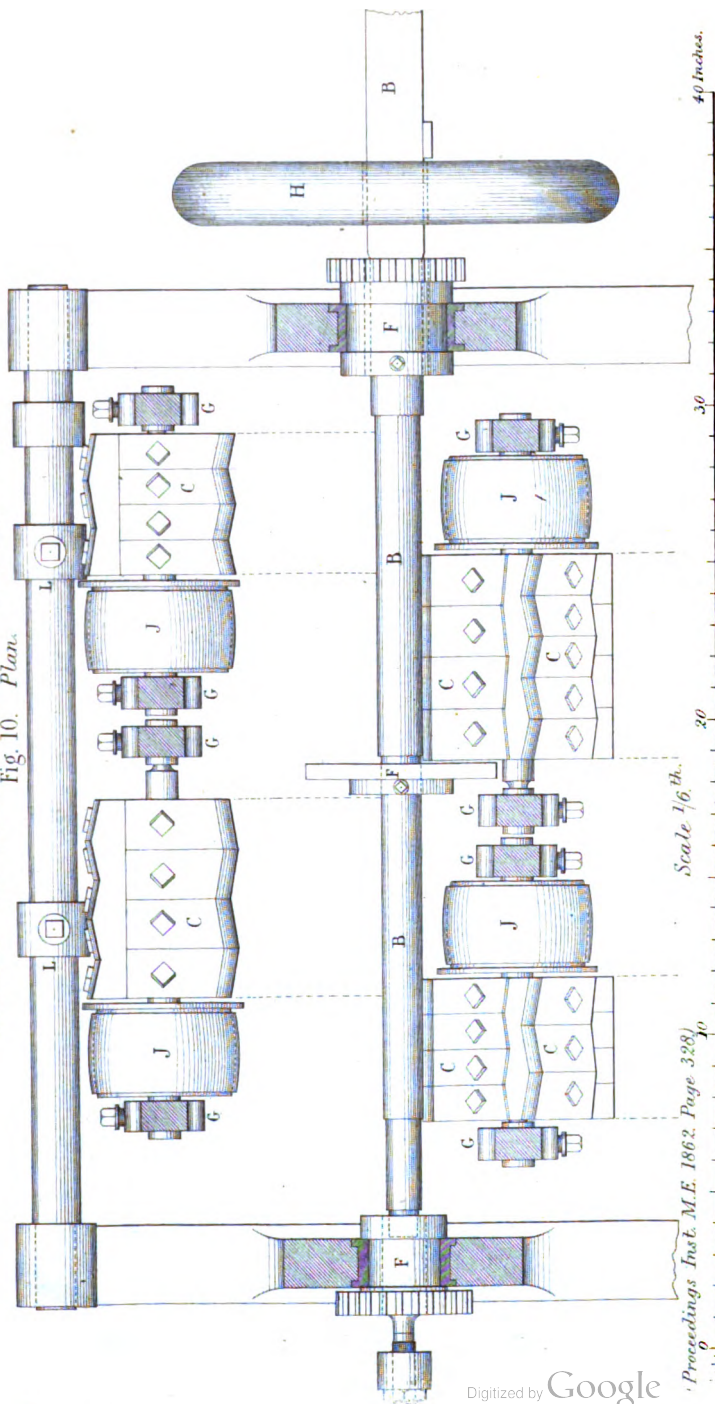
MACHINE FOR SHAPING GUNSTOCK BETWEEN BANDS.

Fig 9. Transverse Section.



GUNSTOCK MACHINERY.
MACHINE FOR SHAPING GUNSTOCK BETWEEN BANDS.

Fig. 10. Plan.



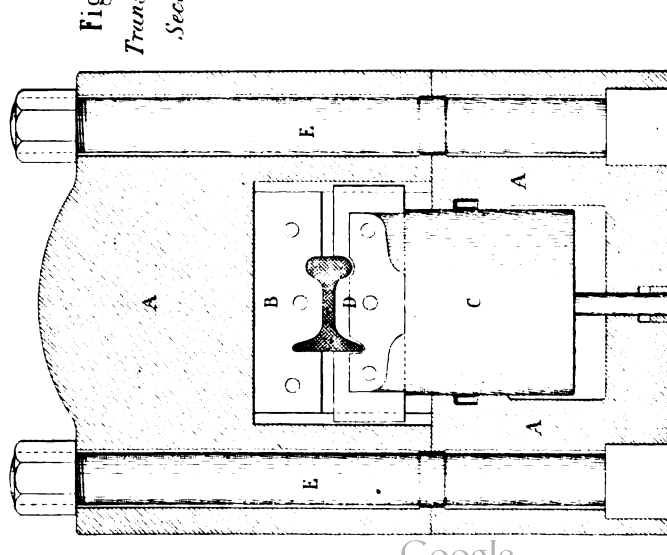


Fig. 1.
*Transverse
Section.*

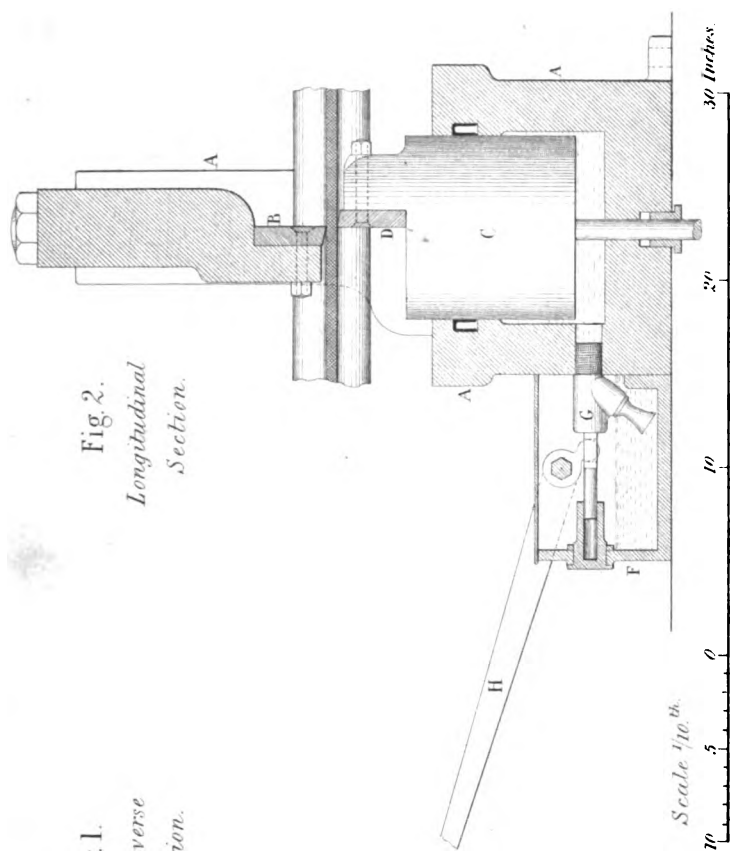


Fig. 2.
*Longitudinal
Section.*

(Proceedings Inst. M. E. 1862. Page 341)

Fig. 3. *Transverse Section.* Fig. 4. *Longitudinal Section.*

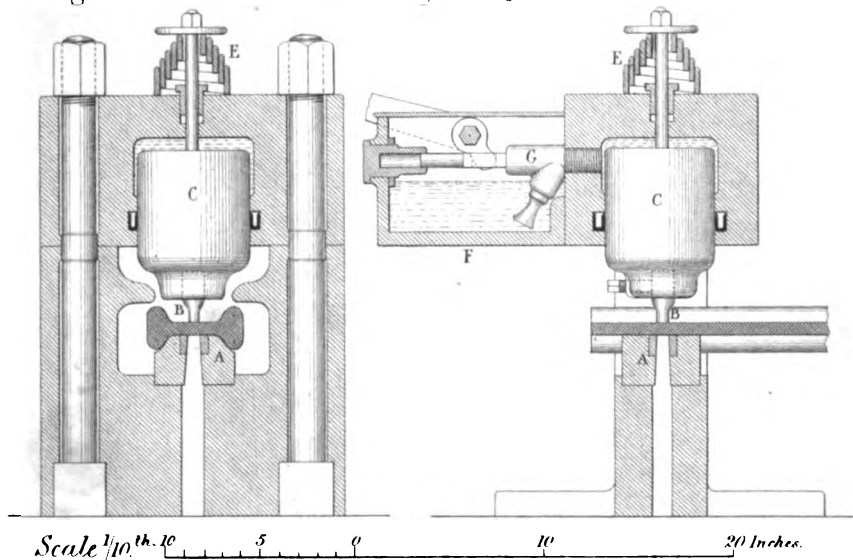


Fig. 5. *Section of Pump, enlarged.*

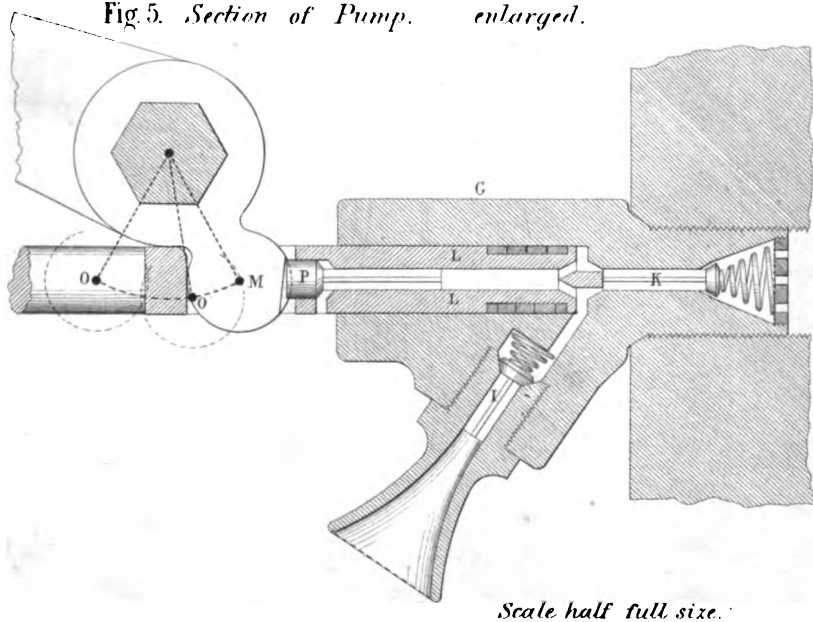


Fig.7. Sectional Plan at XX.

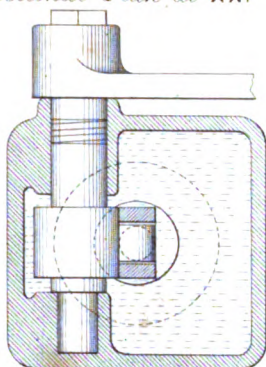


Fig.8.
Sectional
Plan at YY.

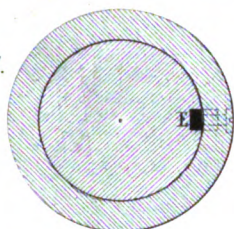


Fig.9. Section of Pump, enlarged.

Scale
half full size.

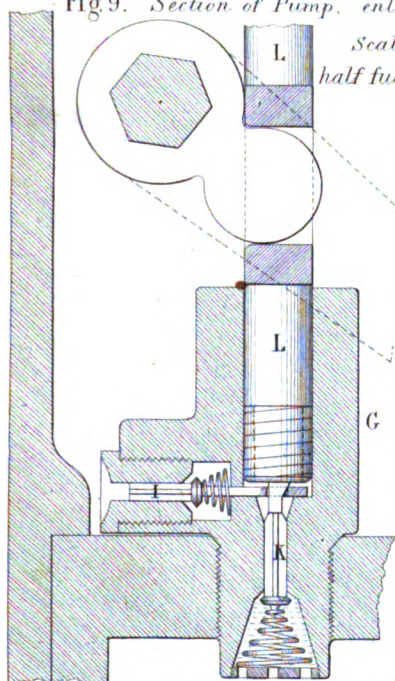
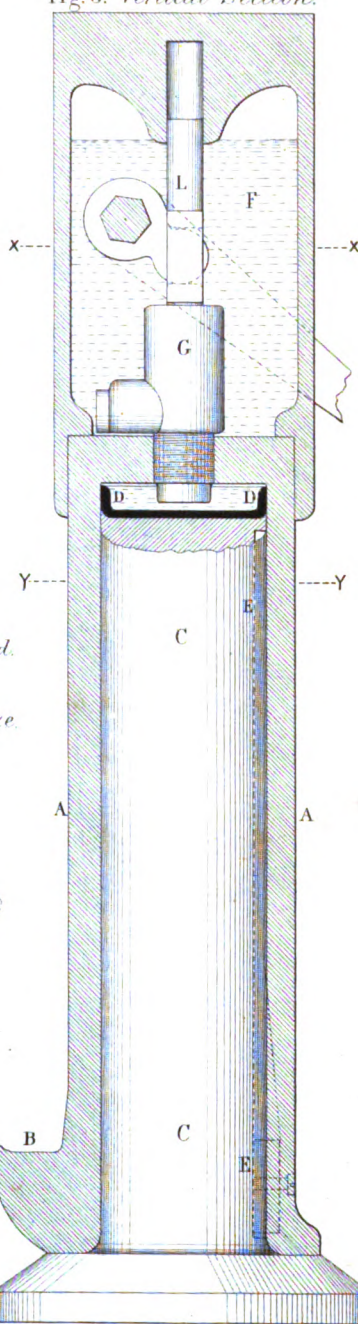


Fig.6. Vertical Section.



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